NASA-DoD Lead-Free Electronics Project

Project Plan

March 2010

National Aeronautics and Space Administration

Technology Evaluation for Environmental Risk Mitigation Principal Center

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1.0 Background

The Joint Council on Aging Aircraft and Joint Group on Pollution Prevention Lead-Free Solder Project (JCAA/JGPP LFS) began in 2001. The goal of the project was to study the effects of environmental testing on the relative reliability of lead-free and tin-lead (SnPb) solder joints and provide baseline data from the evaluation of lead-free solders and termination finishes. The testing conducted for that project generated critical reliability data for aerospace and defense applications as documented in the Joint Test Report (JTR). A copy of the JTR can be found on the NASA Technology Evaluation for Environmental Risk Mitigation (TEERM) Principal Center website.

The NASA-DoD Lead-Free Electronics Project testing will build on the results from the JCAA/JGPP LFS Project focusing on the rework of SnPb and lead-free solder alloys and will include the mixing of SnPb and lead-free solder alloys. The majority of testing being conducted for this effort will mirror the testing completed for JCAA/JGPP LFS Project. Some changes were made in order to optimize the usefulness of the data. The Joint Test Protocol for the NASA-DoD Lead-Free Electronics Project can be found on the NASA TEERM {http://teerm.nasa.gov/NASA_DODLeadFreeElectronics_Proj2.html}.

2.0 Goals

- Generate reliability data for circuit cards manufactured and reworked with SnPb and lead-free solders and subjected to rigorous environmental exposure conditions.
- Provide baseline data for aerospace and defense (high-reliability) applications.

2.1 Key Question Being Addressed

To what extent do rework procedures, including SnPb and lead-free mixed solder joints, affect solder joint reliability of high-performance electronics using SnPb as a baseline?

3.0 Stakeholders

The following is a list of participating stakeholders:

- NASA
- DMEA
- NAVSEA-Crane
- Air Force
- Raytheon
- ITB, Inc.
- Sandia National Laboratories
- Rockwell Collins
- Boeing
- BAE Systems
- Lockheed Martin
- Harris
- COM DEV
- General Dynamics
- Celestica
- Texas Instruments
- Honeywell
- Scorpio Solutions
- Nihon Superior
- PWB Interconnect Solutions

4.0 Project Management

The project is being managed by Kurt Kessel from the NASA Technology Evaluation for Environmental Risk Mitigation (TEERM) Principal Center.

5.0 Project Activities

Table 1 Project Activities

Project Activity	Responsible Party
Procurement	
Procurement of components and boards, includes tinning of component leads	NAVSEA Crane Lockheed Martin
Component Characterization	
Component Characterization	Rockwell Collins, COM DEV, Boeing
Assembly	
Surface Mount Assembly and SnPb wave soldering	BAE Systems
Lead-free wave soldering	Scorpio Solutions
Assembly Characterization	
Micro-section analysis of as assembled test vehicles	General Dynamics
Micro-section analysis of as assembled test vehicles	Sandia National Laboratories
Assembly Inspection	
In-line x-ray evaluation of test vehicle assemblies	Lockheed Martin
Rework	
Extra, Characterization, Vibration and Combined Environments Test Vehicles	BAE Systems
Thermal Cycle, -55 to +125^{o}C and -20 to +80^{o}C Test Vehicles	Lockheed Martin
Mechanical Shock and Drop Testing Test Vehicles	Rockwell Collins
Rework Characterization	
1 component from each of the 4 component types (BGA, CSP, PDIP, TSOP) being reworked from each of the 3 types of rework boards (SnPb, SnPb-ENIG, LF).	Rockwell Collins
Thermal Aging	
All test vehicles to be aged, 100^{o}C for 24 hours	BAE Systems
Testing	
Thermal Cycling -55 to +125^{o}C	Rockwell Collins
Thermal Cycling -20 to +80^{o}C	Boeing
Vibration	Boeing
Combined Environments	Raytheon
Drop Testing	Celestica
Mechanical Shock	Boeing / Nihon Superior
Interconnect Stress Testing (IST)	PWB Interconnect Solutions
Failure Analysis	
Micro-section analysis	Rockwell Collins, Boeing, Nihon Superior, COM DEV, others TBD

6.0 Materials

6.1 Solder Alloys

The lead-free solder alloys selected for this project are:

- SAC305 – Sn3.0Ag0.5Cu – reflow soldering
  - Tin (Sn); Silver (Ag); Copper (Cu)
- SN100C – Sn-0.7Cu-0.05Ni + Ge – reflow and wave soldering
  - Tin (Sn); Copper (Cu); Nickel (Ni); Germanium (Ge)

Selection criteria of prime importance included commercial availability, industry trends, and past reliability testing performance.

Table 2 Solder Alloy and Processes

Solder Alloy	Solder Process		
	Reflow	Wave	Manual
SAC305	X	N/A	X
SN100C	X	X	X
SnPb baseline	X	X	X

N/A = Due to limitations on board numbers and components, these solder alloys were not used during the noted assembly processes

6.1.1 SAC305 – Sn3.0Ag0.5Cu

SnAgCu solder alloys are believed to be the leading choice of the commercial electronics industry for lead-free solder. The Sn3.0Ag0.5Cu is recommended by industry and research consortia as a prime candidate for replacing SnPb solder. Sn3.0Ag0.5Cu is commercially available and currently used in electronic applications. It has been determined that alloys with compositions within the range of Sn3.0-4.0Ag0.5-1.0Cu all have a liquidus temperature around 217°C and have similar microstructures and mechanical properties.

This alloy was chosen for reflow soldering because this particular solder alloy has shown the most promise as a primary replacement for tin-lead solder. The team decided that they wanted to select at least one "general purpose" alloy to be evaluated and it was determined that the SnAgCu solder alloy would best serve this purpose. Conclusions drawn from literature suggest that this alloy has good mechanical properties and may be as reliable as SnPb in some applications.

BAE Systems reviewed several SAC305 solder alloys for printing, reflow, and cleaning characteristics before choosing EnviroMark™ 907 from Kester.

6.1.2 SN100C – Sn0.7Cu0.05Ni(≤0.01Ge)

This alloy is commercially available and the general trend in industry has been to switch to the nickel stabilized tin-copper alloy over standard tin-copper due to its superior performance. In addition, this nickel-stabilized alloy does not require special solder pots and has shown no joint failures in specimens with over four (4) years of service. The cost of this alloy in the form of bar solder is relatively low when compared to other lead-free solder alloys in bar form.

The superior performance of the tin-copper-nickel alloy has been confirmed by university research which has found that the nickel addition works by facilitating solidification of the alloy as a fine uniform eutectic structure and suppressing the growth of primary tin dendrites that are the cause of shrinkage defects in the unmodified alloy. This mode of solidification enhances the fluidity of the alloy close to the melting point, a property that is important in a solder so that it is comparable with that of tin-lead solder at the same superheat. The tin-copper-nickel alloy is representative of a new class of modified tin-copper solders that are increasing in popularity as the limitations of the tin-silver-copper alloys in some applications become apparent.

Nihon Superior SN100C will be used for this project.

6.2 Flux

The flux systems used during soldering were "low residue" or no-clean fluxes and the group chose to clean the test vehicles after processing even though no-clean fluxes were used with some solders. Additionally, reflow was accomplished without nitrogen inerting, which might have created a smaller soldering process window (a credit to the BAE Systems crew for creating a quality test vehicle under such tough process conditions).

Table 3 Solder Alloys and Associated Flux

Solder Alloy	Flux		
	Reflow Soldering	Wave Soldering	Manual Soldering
SAC305	ROL1	N/A	ROL0 Tacky Flux
SN100C	ROL0	ORL0	ROL0 Tacky Flux
SnPb baseline	ROL0	ORM0	ROL0 Tacky Flux

- Table provided by BAE Systems Irving, Texas
- During rework, flux was only used for BGA rework
- N/A = Due to limitations on board numbers and components, these solder alloys were not used during the noted assembly processes
- R = Rosin base
- {IPC J-STD-004B; Table 1-1, Flux Identification System}
  - ROL0 = Rosin, Low flux/flux residue activity, < 0.05% halide
  - ROL1 = Rosin, Low flux/flux residue activity, < 0.5% halide
  - ORL0 = Organic, Low flux/flux residue activity, < 0.05% halide
  - ORM0 = Organic, Moderate flux/flux residue activity, < 0.05% halide

6.3 Board Material

Project stakeholders selected FR4 per IPC-4101/26 with a minimum Tg of 170ºC for the test vehicles. Pho-Tronics supplied the circuit cards and used Isola 370HR laminate.

6.4 Board Finish

Project stakeholders and participants selected immersion silver (.2 - .4 microns; MacDermid Sterling) as the surface finish for the majority of the test vehicles. The consensus of the project team was that immersion silver has the best balance of desirable properties: good wetting by solders, good solder joint reliability, good long-term solderability upon storage, and retention of solderability after multiple reflow cycles. In addition, several major electronic manufacturing companies are currently using immersion silver in production.

A limited number of test vehicles were assembled using an Electroless Nickel Immersion Gold (ENIG) surface finish (Uyemura Kat 450 ENIG). The project stakeholders felt that ENIG would be a good secondary surface finish since it provides good planarity and solderability which can withstand multiple reflows. ENIG has also been shown to perform well with regards to substrate shelf-life, corrosion resistance, assembly process window, thermal resistance over several temperature excursions, and reworkability.

6.5 Components

The project stakeholder's agreed to populate the test vehicles with the following components:

Table 4 Components Table

20LCC-1.27mm-8.90mm-DC-L-Au = **Tinning-SAC305**
20LCC-1.27mm-8.90mm-DC-L-Au = **Tinning-SnPb**
A-MLF20-5mm-.65mm-DC(30467)
A-MLF20-5mm-.65mm-DC-Sn(30801)
A-TQFP144-20mm-.5mm-2.0-DC-Sn(30643)
A-TQFP144-20mm-.5mm-2.0-DC-NiPdAu
A-TQFP144-20mm-.5mm-2.0-DC-Sn(30643) = **Tinning-SAC305**
A-TQFP144-20mm-.5mm-2.0-DC-Sn(30643) = **Tinning-SnPb**
PBGA225-1.5mm-27mm-DC(10565)
PBGA225-1.5mm-27mm-DC-LF(16074)
A-PDIP20T-7.6mm-DC-Sn (30737)
PDIP20T-DC (12006)
PDIP-20 - NiPdAu
A-CABGA100-.8mm-10mm-DC(30102)
A-CABGA100-.8mm-10mm-DC-LF(30695)
A-CABGA100-.8mm-10mm-DC-105
A-TII-TSOP50-10.16x20.95mm-.8mm-DC-TR
A-TII-TSOP50-10.16x20.95mm-.8mm-DC-SnBi-TR
A-TII-TSOP50-10.16x20.95mm-.8mm-DC-Sn-TR

Note – The TSOP-50 components do not have a dummy die. For more information on the decision not to include dummy die, please see Appendix A

7.0 Component Characterization

Destructive Physical Analysis (DPA) will be performed on samples from each of the component types being placed onto the test vehicles. The DPA process is being used to ensure that the components being used for testing meet the consortia required standards and to evaluate the quality of construction. A worksheet (Appendix B) has been developed to ensure that all locations performing DPA collect the same information.

8.0 Test Vehicle Assemblies

The following section has been organized by how BAE Systems will process the test vehicles.

8.1 Break-Off Coupons

Break-off coupons will be divided into two groups, those that will be processed through reflow and wave solder processing and those that will be removed prior to reflow and wave solder processing. The break-off coupons will be divided by Batch.

8.1.1 Break-Off Coupon Breakdown

8.1.1.1 Break-off coupons that will remain during soldering

Break-off coupons will remain on the following test vehicles through reflow and wave solder processing:

- Lead-Free Rework (Batch A)
- SnPb Manufactured (Batch C)
- Lead-Free Manufactured (Batch E)
- Lead-Free Manufactured (Batch G)
- Lead-Free Manufactured (Batch H)
- Lead-Free Manufactured (Batch I)

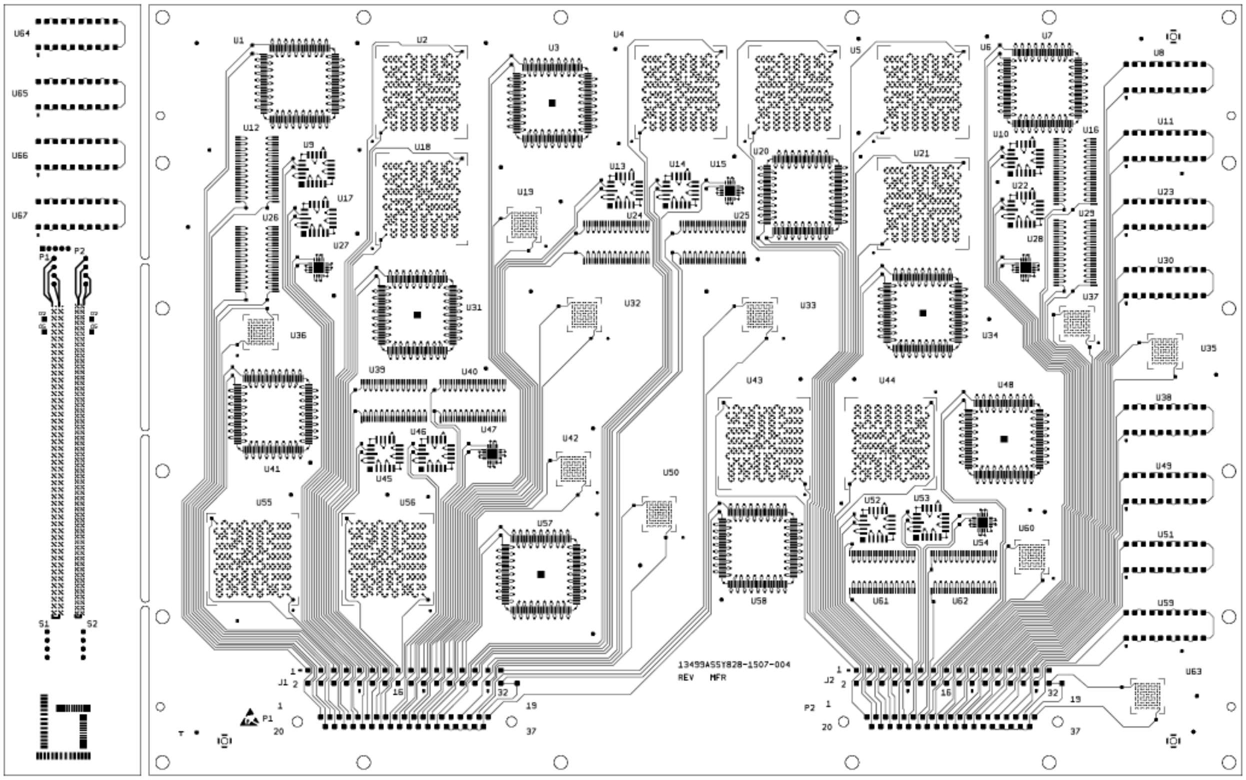


Figure 1 Test Vehicle with Break-Off Coupon Attached

8.1.1.2 **Break-off coupons that will be removed before soldering**

Break-off coupons will be removed from the following test vehicles prior to reflow and wave solder processing:

- SnPb Rework (Batch B)
- SnPb Manufactured (Batch D)
- Lead-Free Manufactured (Batch F)

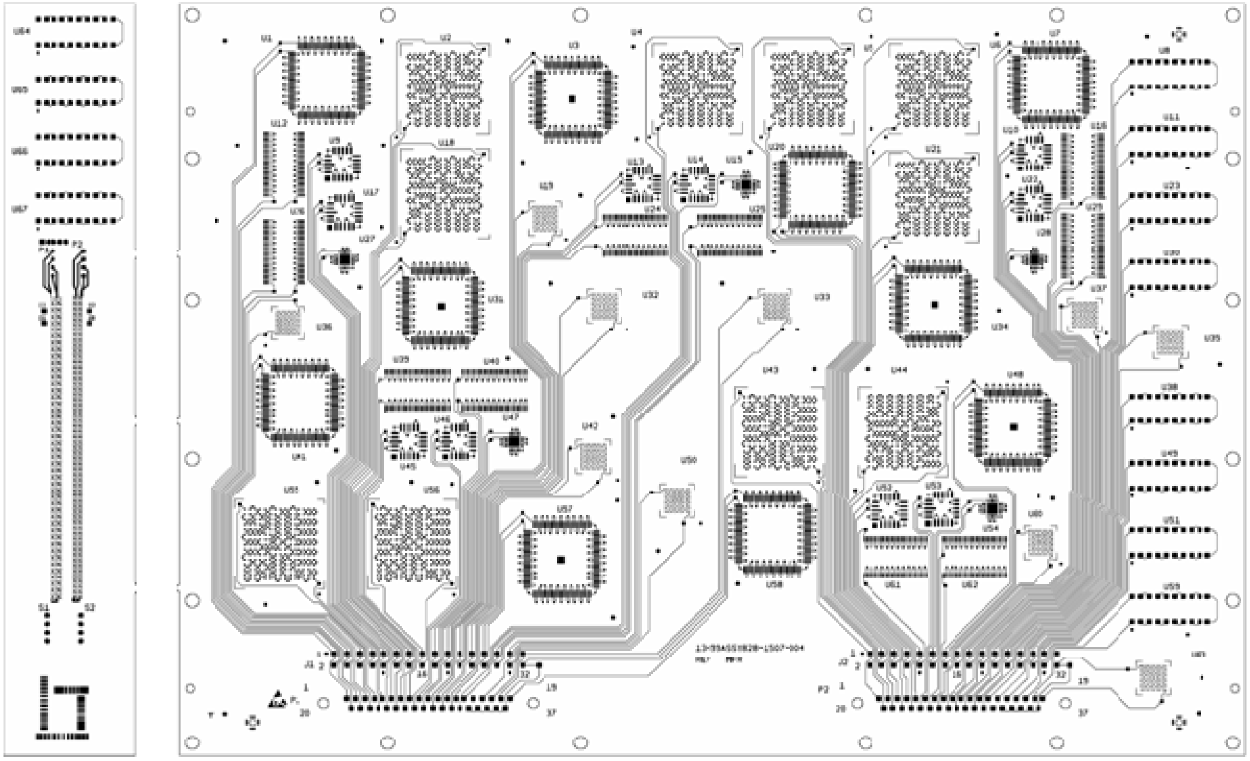


Figure 2 Test Vehicle with Break-Off Coupon Removed

8.1.2 Break-Off Coupon Processing

- Break-off coupons that go through lead-free reflow and wave soldering will be removed by Scorpio Solutions and shipped to BAE Systems for capacitance measurements. BAE Systems will then ship the break-off coupons to Rockwell Collins to be divided into three separate pieces, two copper dissolution coupons and one IST coupon.
- Break-off coupons that go through SnPb reflow and wave soldering will be removed by BAE Systems and shipped to Rockwell Collins to be divided into the three separate pieces.
- Break-off coupons that will not be processed through reflow solder processing will be removed by BAE Systems and shipped to PWB Interconnect Solutions for IST testing.

8.1.3 Break-Off Coupon Pieces

a. Copper dissolution coupon (plated through hole). The plated through hole pattern has serial reduction in hole size to simulate the various aspect ratios possible in through-hole soldering and the effects of the barrel (plated copper) when exposed to rework conditions. Additional details are contained in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

b. IST coupon. Coupons are designed to determine if thermal processing degrades via reliability and promotes board delamination. Additional details are contained in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

c. Copper dissolution coupon (surface trace). The surface trace feature (Foil copper) of the coupon has been included to evaluate the effect on surface features exposed to rework. Additional details are contained in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

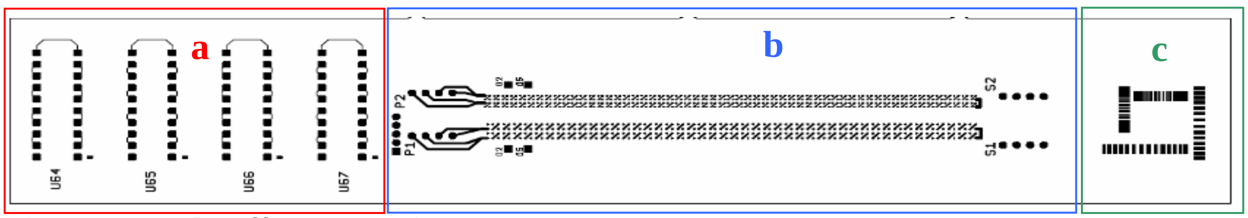


Figure 3 Break-Off Coupon Pieces

8.2 Test Vehicle Break Out

Due to the various types of test vehicles being assembled, BAE Systems will assemble the test vehicles in multiple batches.

Table 5 Test Vehicle Batch Key

Test Vehicle Type	Reflow Solder	Wave Solder	Batch (Section Number)	Serial Numbers	Number of Boards
Lead-Free Rework All Test Vehicles	SAC305	SN100C	A (8.3)	161-193	33
SnPb Rework* All Test Vehicles	SnPb*	SnPb*	B (8.4)	121-160	40
SnPb Manufactured Test Vehicles Thermal Cycle and Combined Environments Tests	SnPb	SnPb	C (8.5)	1, 3, 5–14, 20 - 24	17
SnPb Manufactured Test Vehicles Vibration, Mechanical Shock and Drop Tests	SnPb	SnPb	D (8.6)	2, 4, 15–19, 25-34	17
Lead-Free Manufactured Test Vehicles Thermal Cycle and Combined Environments Tests	SAC305	SN100C	E (8.7)	35, 39, 41-45, 50-54, 69-73, 93, 95, 97	20
Lead-Free Manufactured Test Vehicles Vibration, Mechanical Shock and Drop Tests	SAC305	SN100C	F (8.8)	36-38, 40, 46-49, 55-68, 74-92, 94, 96	43
Lead-Free Manufactured Test Vehicles Thermal Cycle and Combined Environments Tests	SN100C	SN100C	G (8.9)	100, 102-106, 116-120	11
Lead-Free Manufactured Test Vehicles Vibration, Mechanical Shock and Drop Tests	SN100C	SN100C	H (8.10)	101, 111-115	6
Lead-Free Manufactured Test Vehicles Crane Rework Effort	SN100C	SN100C	I (8.11)	98-99, 107-110	6

* NOTE: Lead-Free profiles will be used for reflow and wave soldering

8.3 Lead-Free Rework (Batch A)

8.3.1 Bare Boards

- 33 boards
- 14.5”X 9”X 0.09”
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag surface finish

Table 6 Test Vehicle Tracker – Lead-Free Rework Test Vehicles (Batch A)

Project Activity	Board Number	Board Finish
Extra Boards	SN179	Immersion Ag
Test Vehicle Characterization	SN161	
Thermal Cycling: -55C to +125C	SN164 – SN168	
Thermal Cycling: -20C to +80C	SN169 – SN173	
Vibration	SN174 – SN178	
Combined Environments Testing	SN163	
	SN180 – SN183	
Drop Testing	SN184 – SN188	
Mechanical Shock	SN189 – SN193	

Table 7 Component Finish Matrix – Lead-Free Rework Test Vehicles (Batch A)**

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U18	BGA-225	SAC405	SAC305	
U43	BGA-225	SAC405	SAC305	
U06	BGA-225	SAC405	SAC305	
U02	BGA-225	SAC405	SAC305	
U21	BGA-225	SAC405	SAC305	
U56	BGA-225	SAC405	SAC305	
U04	BGA-225	SnPb	SAC305	
U55	BGA-225	SnPb	SAC305	
U05	BGA-225	SnPb	SAC305	
U44	BGA-225	SnPb	SAC305	
U09	CLCC-20	SnPb	SAC305	
U13	CLCC-20	SnPb	SAC305	
U22	CLCC-20	SnPb	SAC305	
U46	CLCC-20	SnPb	SAC305	
U53	CLCC-20	SnPb	SAC305	
U10	CLCC-20	SnPb	SAC305	
U14	CLCC-20	SnPb	SAC305	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U17	CLCC-20	SnPb	SAC305	
U45	CLCC-20	SnPb	SAC305	
U52	CLCC-20	SnPb	SAC305	
U33	CSP-100	SAC105	SAC305	
U50	CSP-100	SAC105	SAC305	
U19	CSP-100	SAC105	SAC305	
U37	CSP-100	SAC105	SAC305	
U42	CSP-100	SAC105	SAC305	
U60	CSP-100	SAC105	SAC305	
U36	CSP-100	SAC105	SAC305	
U32	CSP-100	SnPb	SAC305	
U35	CSP-100	SnPb	SAC305	
U63	CSP-100	SnPb	SAC305	
U08	PDIP-20	Sn		SN100C
U23	PDIP-20	Sn		SN100C
U49	PDIP-20	Sn		SN100C
U59	PDIP-20	Sn		SN100C
U30	PDIP-20	Sn		SN100C
U38	PDIP-20	Sn		SN100C
U11	PDIP-20	Sn		SN100C
U51	PDIP-20	Sn		SN100C
U15	QFN	SnPb	SAC305	
U27	QFN	SnPb	SAC305	
U28	QFN	SnPb	SAC305	
U47	QFN	SnPb	SAC305	
U54	QFN	SnPb	SAC305	
U03	TQFP-144	NiPdAu	SAC305	
U31	TQFP-144	NiPdAu	SAC305	
U34	TQFP-144	NiPdAu	SAC305	
U48	TQFP-144	NiPdAu	SAC305	
U57	TQFP-144	NiPdAu	SAC305	
U01	TQFP-144	SAC 305 Dip	SAC305	
U07	TQFP-144	SAC 305 Dip	SAC305	
U20	TQFP-144	SAC 305 Dip	SAC305	
U41	TQFP-144	SAC 305 Dip	SAC305	
U58	TQFP-144	SAC 305 Dip	SAC305	
U12	TSOP-50	Sn	SAC305	
U25	TSOP-50	Sn	SAC305	
U29	TSOP-50	SnBi	SAC305	
U39	TSOP-50	SnBi	SAC305	
U61	TSOP-50	SnBi	SAC305	
U24	TSOP-50	SnBi	SAC305	

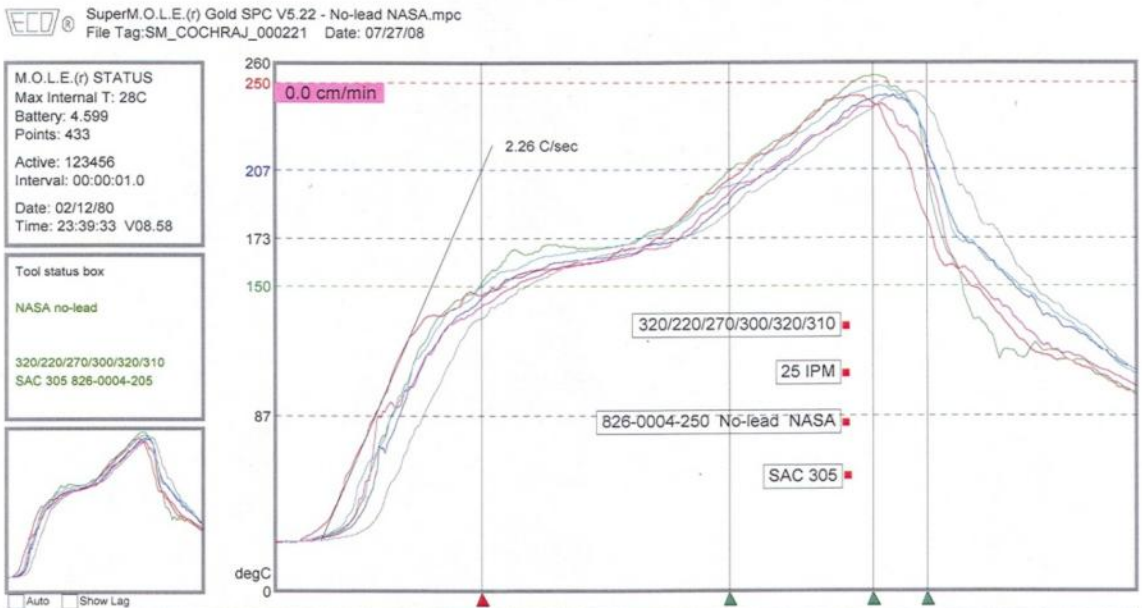
RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U26	TSOP-50	SnBi	SAC305	
U16	TSOP-50	SnPb	SAC305	
U40	TSOP-50	SnPb	SAC305	
U62	TSOP-50	SnPb	SAC305	

** This table shows the termination finishes and solder alloys being used for initial manufacturing only. See Table 34 for the termination finishes and solder alloys being used for rework.

8.3.2 Assembly Details

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SAC305
  - Preheat = 60-120 seconds @150-190°C
  - Peak temperature target = 243°C
  - Reflow:~20 seconds above 230°C
  - ~30-90 seconds above 220°C

- Wave Soldering
- Location – Scorpio Solutions
- Wave Profile = SN100C
  - Solder Pot Temperature = 265°C
  - Preheat Board T = 134°C
  - Peak Temperature = 155°C to 175°C
  - Speed: 90 cm/min

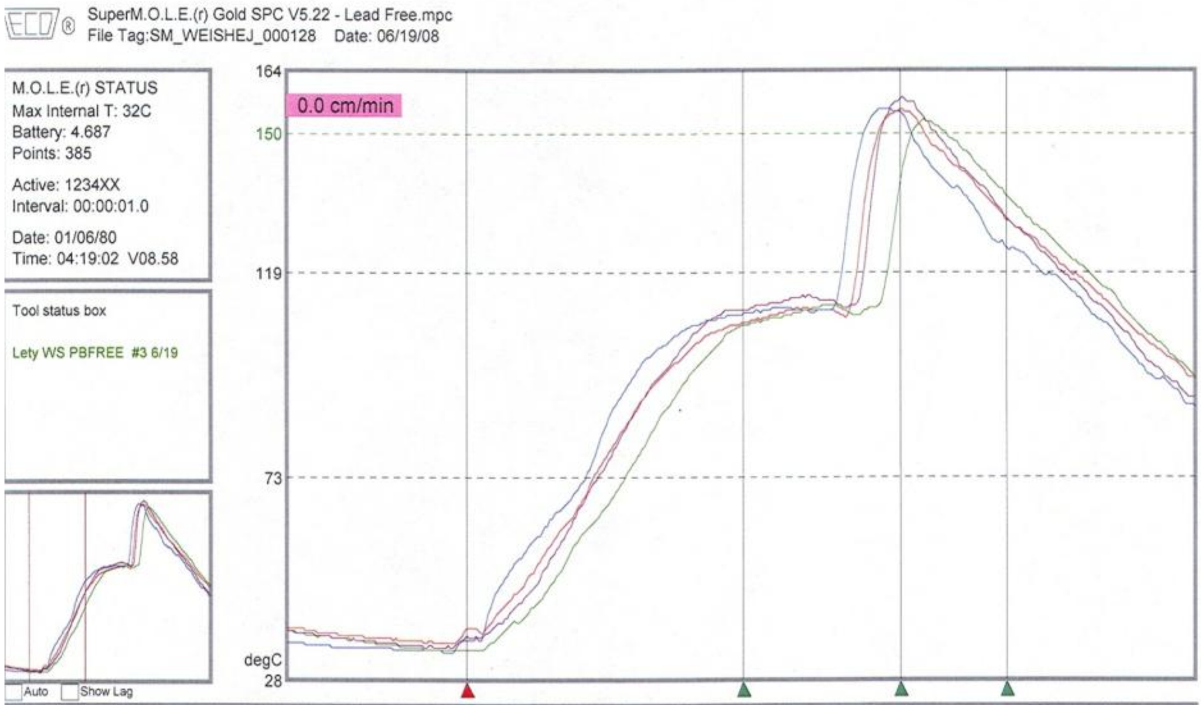


Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
South of U37 CSP	146	203	239	182	degC
North of U32 hybrid	144	193	242	218	degC
North of U42 CSP	151	207	253	204	degC
North of U4	140	196	238	209	degC
South of U58	149	199	248	216	degC
North of U36 CSP	134	187	237	238	degC

T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
North of U4	00:03:54	00:01:21	00:00:00	0%	Time
South of U58	00:04:29	00:01:33	00:00:00	0%	Time
North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Figure 4 Reflow Oven Profile – Lead-Free (SAC305)



Value	C1 = 00:01:16 r	C2 = 00:03:13 r	C3 = 00:04:19 r	C4 = 00:05:04 r	Units
Near U44	39	108	156	131	degC
Near U35	37	110	155	124	degC
Near U41	34	107	139	136	degC
center of board	38	111	158	131	degC
Sensor 5 Location.					
Sensor 6 Location.					

T Above Ref	Low = 150	Med = 180	Hi = 183	Cure Factor	Units
Near U44	00:00:20	00:00:00	00:00:00	0%	Time
Near U35	00:00:21	00:00:00	00:00:00	0%	Time
Near U41	00:00:15	00:00:00	00:00:00	0%	Time
center of board	00:00:24	00:00:00	00:00:00	0%	Time
Sensor 5 Location.					
Sensor 6 Location.					

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
Near U44	36	00:00:58 r	156	00:04:19 r	91.4	38.3	degC
Near U35	34	00:01:06 r	156	00:04:10 r	91.4	38.1	degC
Near U41	34	00:00:58 r	153	00:04:29 r	88.4	39.1	degC
center of board	35	00:00:58 r	158	00:04:20 r	90.8	39.1	degC
Sensor 5 Location.							
Sensor 6 Location.							

Figure 5 Wave Solder Profile – Lead-Free (SN100C)

8.4 SnPb Rework (Batch B)

8.4.1 Bare Boards

- 40 boards
- 14.5”X 9”X 0.09”
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag and ENIG surface finishes

Table 8 Test Vehicle Tracker – SnPb Rework Test Vehicles (Batch B)

Project Activity	Board Number	Board Finish	Board Number	Board Finish
Extra Boards	SN121 – SN122	Immersion Ag	N/A	ENIG
Test Vehicle Characterization	SN123		SN154	
Thermal Cycling: -55C to +125C	SN124 – SN128		SN155	
Thermal Cycling: -20C to +80C	SN129 – SN133		SN156	
Vibration	SN134 – SN138		SN157	
Combined Environments Testing	SN139 – SN143		SN158	
Drop Testing	SN144 – SN148		SN159	
Mechanical Shock	SN149 – SN153		SN160	

*All test vehicles in Batch B were exposed to extended thermal aging, 4 days, per Section 12.0.

Table 9 Component Finish Matrix – SnPb Rework Test Vehicles (Batch B)**

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U04	BGA-225	SAC405	SnPb	
U55	BGA-225	SAC405	SnPb	
U05	BGA-225	SAC405	SnPb	
U44	BGA-225	SAC405	SnPb	
U18	BGA-225	SnPb	SnPb	
U43	BGA-225	SnPb	SnPb	
U06	BGA-225	SnPb	SnPb	
U02	BGA-225	SnPb	SnPb	
U21	BGA-225	SnPb	SnPb	
U56	BGA-225	SnPb	SnPb	
U09	CLCC-20	SAC305	SnPb	
U13	CLCC-20	SAC305	SnPb	
U22	CLCC-20	SAC305	SnPb	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U46	CLCC-20	SAC305	SnPb	
U53	CLCC-20	SAC305	SnPb	
U10	CLCC-20	SAC305	SnPb	
U14	CLCC-20	SAC305	SnPb	
U17	CLCC-20	SAC305	SnPb	
U45	CLCC-20	SAC305	SnPb	
U52	CLCC-20	SAC305	SnPb	
U32	CSP-100	SAC105	SnPb	
U35	CSP-100	SAC105	SnPb	
U63	CSP-100	SAC105	SnPb	
U36	CSP-100	SAC105	SnPb	
U33	CSP-100	SnPb	SnPb	
U50	CSP-100	SnPb	SnPb	
U19	CSP-100	SnPb	SnPb	
U37	CSP-100	SnPb	SnPb	
U42	CSP-100	SnPb	SnPb	
U60	CSP-100	SnPb	SnPb	
U08	PDIP-20	NiPdAu		SnPb
U23	PDIP-20	NiPdAu		SnPb
U49	PDIP-20	NiPdAu		SnPb
U59	PDIP-20	Sn		SnPb
U30	PDIP-20	Sn		SnPb
U38	PDIP-20	Sn		SnPb
U11	PDIP-20	SnPb		SnPb
U51	PDIP-20	SnPb		SnPb
U15	QFN	Matte Sn	SnPb	
U27	QFN	Matte Sn	SnPb	
U28	QFN	Matte Sn	SnPb	
U47	QFN	Matte Sn	SnPb	
U54	QFN	Matte Sn	SnPb	
U03	TQFP-144	NiPdAu	SnPb	
U31	TQFP-144	NiPdAu	SnPb	
U34	TQFP-144	NiPdAu	SnPb	
U48	TQFP-144	NiPdAu	SnPb	
U57	TQFP-144	NiPdAu	SnPb	
U01	TQFP-144	SnPb Dip	SnPb	
U07	TQFP-144	SnPb Dip	SnPb	
U20	TQFP-144	SnPb Dip	SnPb	
U41	TQFP-144	SnPb Dip	SnPb	
U58	TQFP-144	SnPb Dip	SnPb	
U29	TSOP-50	Sn	SnPb	
U39	TSOP-50	Sn	SnPb	
U61	TSOP-50	Sn	SnPb	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U16	TSOP-50	SnBi	SnPb	
U40	TSOP-50	SnBi	SnPb	
U62	TSOP-50	SnBi	SnPb	
U12	TSOP-50	SnPb	SnPb	
U25	TSOP-50	SnPb	SnPb	
U24	TSOP-50	SnPb	SnPb	
U26	TSOP-50	SnPb	SnPb	

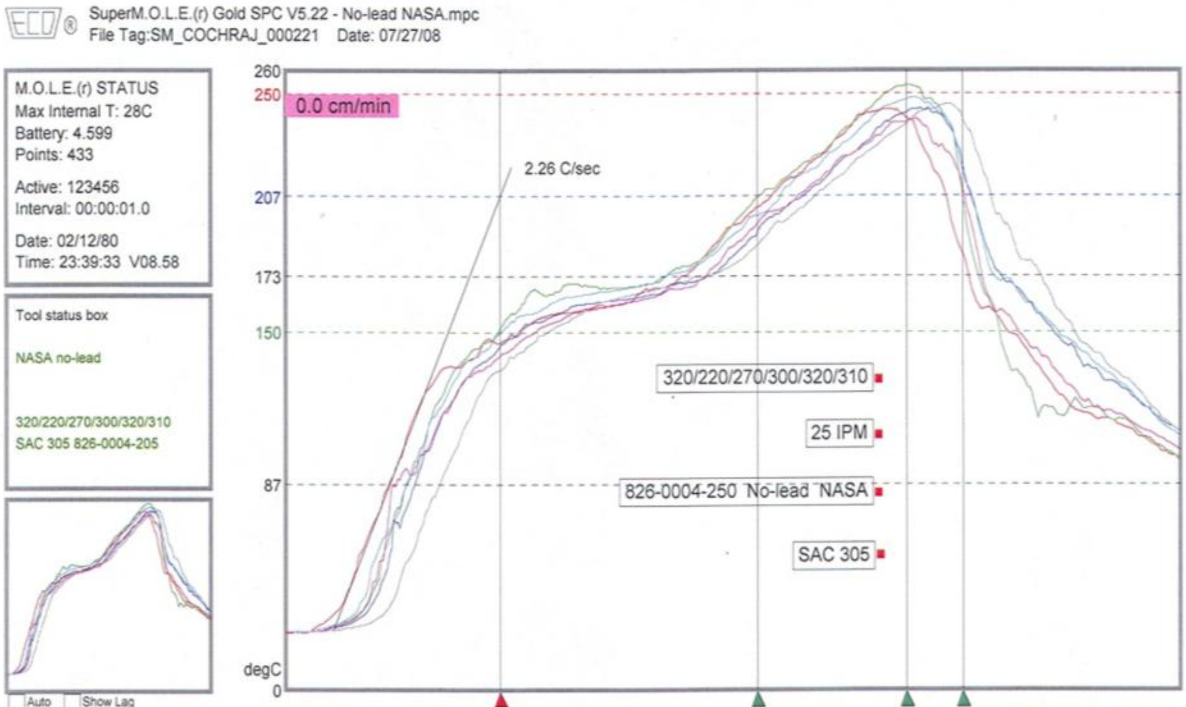
** This table shows the termination finishes and solder alloys being used for manufacturing only. See Table 35 for the termination finishes and solder alloys being used for rework.

8.4.2 Assembly Details

The NASA-DoD Lead-Free Electronics Project consortia members agreed to use higher temperature lead-free reflow and wave soldering profiles in conjunction with SnPb solder alloys for the SnPb Rework Test Vehicles only. The intent is to ensure complete mixing of the SnPb solder paste with the SAC BGA balls which should maximize reliability. Incomplete solder mixing within lead-free solder balls attached with SnPb solder using a SnPb reflow profile is known to give reduced reliability for area array components [1-2].

- Reflow Soldering
- Location - BAE Systems Irving, Texas
- Reflow Profile = SAC305
    - Preheat = 60-120 seconds @150-190°C
    - Peak temperature target = 243°C
    - Reflow:~20 seconds above 230°C
    - ~30-90 seconds above 220°C

- Wave Soldering
- Location - BAE Systems Irving, Texas
- Wave Profile = SN100C
    - Solder Pot Temperature = 265°C
    - Preheat Board T = 134°C
    - Peak Temperature = 157°C
    - Speed: 90 cm/min

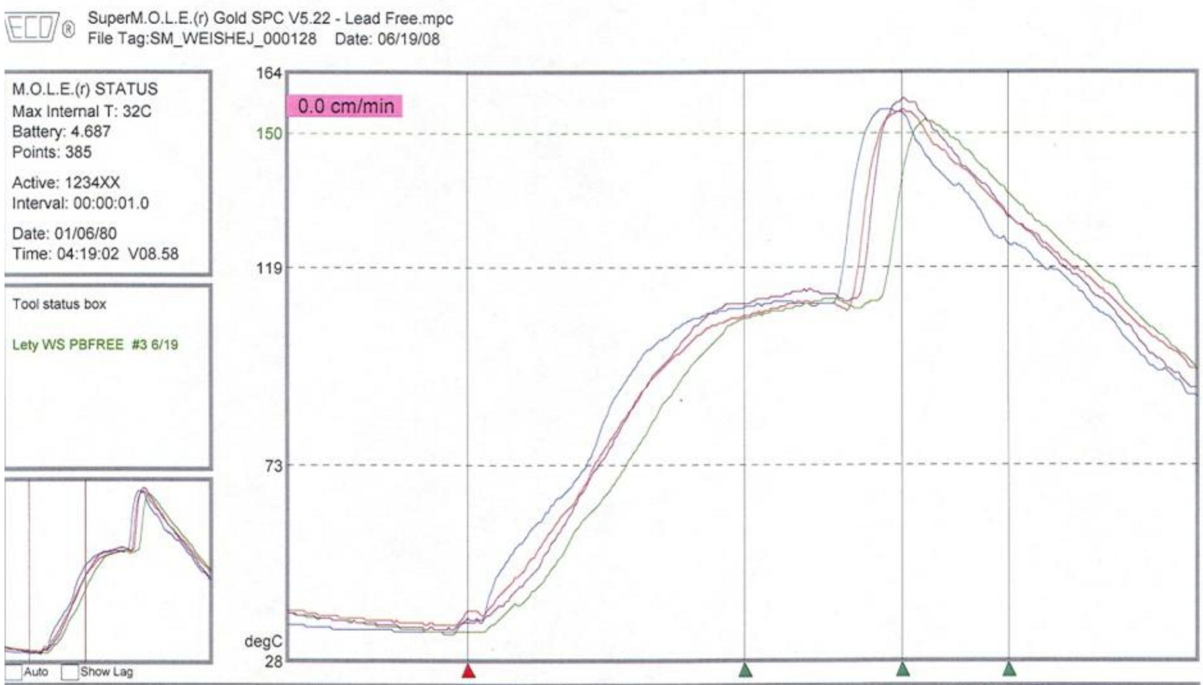


Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
South of U37 CSP	146	203	239	182	degC
North of U32 hybrid	144	193	242	218	degC
North of U42 CSP	151	207	253	204	degC
North of U4	140	196	238	209	degC
South of U58	149	199	248	216	degC
North of U36 CSP	134	187	237	238	degC

T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
North of U4	00:03:54	00:01:21	00:00:00	0%	Time
South of U58	00:04:29	00:01:33	00:00:00	0%	Time
North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Figure 6 Reflow Oven Profile – Lead-Free (SAC305), being used for SnPb Rework Assemblies



Value	C1 = 00:01:16 r	C2 = 00:03:13 r	C3 = 00:04:19 r	C4 = 00:05:04 r	Units
Near U44	39	108	156	131	degC
Near U35	37	110	155	124	degC
Near U41	34	107	139	136	degC
center of board	38	111	158	131	degC
Sensor 5 Location.					
Sensor 6 Location.					

T Above Ref	Low = 150	Med = 180	Hi = 183	Cure Factor	Units
Near U44	00:00:20	00:00:00	00:00:00	0%	Time
Near U35	00:00:21	00:00:00	00:00:00	0%	Time
Near U41	00:00:15	00:00:00	00:00:00	0%	Time
center of board	00:00:24	00:00:00	00:00:00	0%	Time
Sensor 5 Location.					
Sensor 6 Location.					

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
Near U44	36	00:00:58 r	156	00:04:19 r	91.4	38.3	degC
Near U35	34	00:01:06 r	156	00:04:10 r	91.4	38.1	degC
Near U41	34	00:00:58 r	153	00:04:29 r	88.4	39.1	degC
center of board	35	00:00:58 r	158	00:04:20 r	90.8	39.1	degC
Sensor 5 Location.							
Sensor 6 Location.							

Figure 7 Wave Solder Profile – Lead-Free (SN100C), being used for SnPb Rework Assemblies

8.5 SnPb Manufactured (Batch C)

8.5.1 Bare Boards

- 17 boards
- 14.5"X 9"X 0.09"
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag surface finish

Table 10 Test Vehicle Tracker – SnPb Manufactured Test Vehicles (Batch C)

Project Activity	Board Number	Board Finish
Extra Boards	SN1	**Immersion Ag**
Test Vehicle Characterization	SN3	
Thermal Cycling: -55C to +125C	SN5 – SN9	
Thermal Cycling: -20C to +80C	SN10 – SN14	
Combined Environments Testing	SN20 – SN24	

Table 11 Component Finish Matrix – SnPb Manufactured Test Vehicles (Batch C)

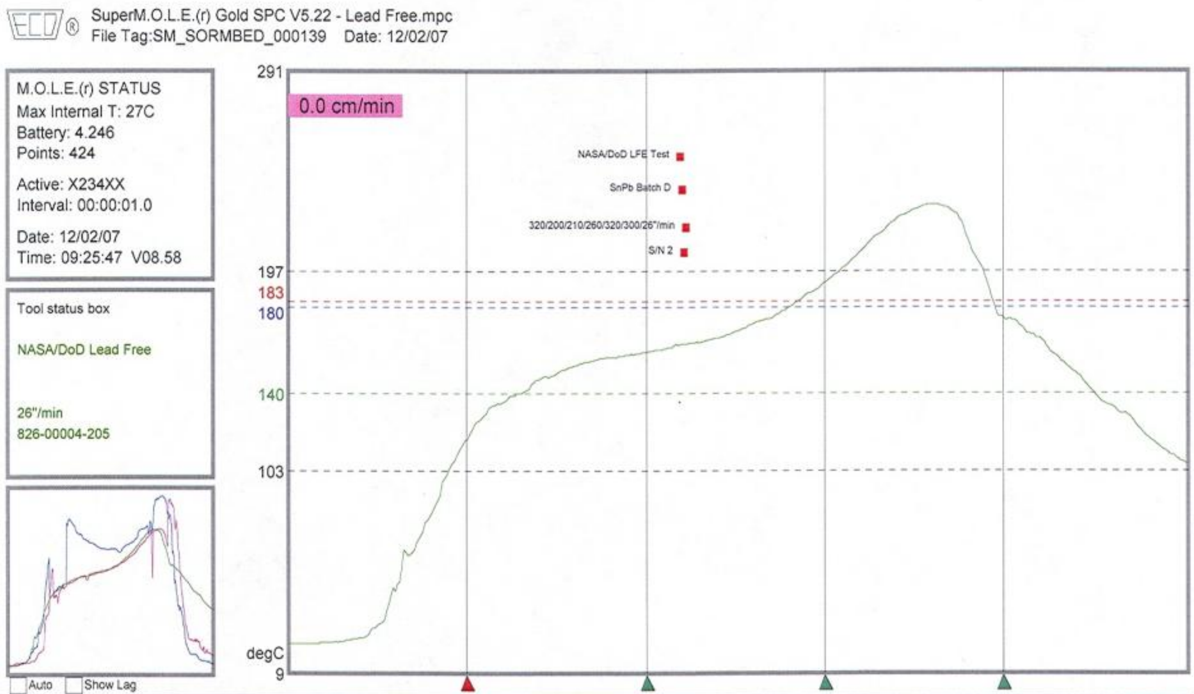
RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U18	BGA-225	SAC405	SnPb	
U43	BGA-225	SAC405	SnPb	
U04	BGA-225	SAC405	SnPb	
U06	BGA-225	SAC405	SnPb	
U55	BGA-225	SAC405	SnPb	
U02	BGA-225	SnPb	SnPb	
U05	BGA-225	SnPb	SnPb	
U21	BGA-225	SnPb	SnPb	
U44	BGA-225	SnPb	SnPb	
U56	BGA-225	SnPb	SnPb	
U09	CLCC-20	SAC305	SnPb	
U13	CLCC-20	SAC305	SnPb	
U22	CLCC-20	SAC305	SnPb	
U46	CLCC-20	SAC305	SnPb	
U53	CLCC-20	SAC305	SnPb	
U10	CLCC-20	SnPb	SnPb	
U14	CLCC-20	SnPb	SnPb	
U17	CLCC-20	SnPb	SnPb	
U45	CLCC-20	SnPb	SnPb	
U52	CLCC-20	SnPb	SnPb	
U32	CSP-100	SAC105	SnPb	
U33	CSP-100	SAC105	SnPb	
U35	CSP-100	SAC105	SnPb	
U50	CSP-100	SAC105	SnPb	
U63	CSP-100	SAC105	SnPb	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U19	CSP-100	SnPb	SnPb	
U36	CSP-100	SnPb	SnPb	
U37	CSP-100	SnPb	SnPb	
U42	CSP-100	SnPb	SnPb	
U60	CSP-100	SnPb	SnPb	
U08	PDIP-20	NiPdAu		SnPb
U23	PDIP-20	NiPdAu		SnPb
U49	PDIP-20	NiPdAu		SnPb
U59	PDIP-20	NiPdAu		SnPb
U11	PDIP-20	Sn		SnPb
U30	PDIP-20	Sn		SnPb
U38	PDIP-20	Sn		SnPb
U51	PDIP-20	Sn		SnPb
U15	QFN	Matte Sn	SnPb	
U27	QFN	Matte Sn	SnPb	
U28	QFN	Matte Sn	SnPb	
U47	QFN	Matte Sn	SnPb	
U54	QFN	Matte Sn	SnPb	
U01	TQFP-144	Matte Sn	SnPb	
U07	TQFP-144	Matte Sn	SnPb	
U20	TQFP-144	Matte Sn	SnPb	
U41	TQFP-144	Matte Sn	SnPb	
U58	TQFP-144	Matte Sn	SnPb	
U03	TQFP-144	SnPb Dip	SnPb	
U31	TQFP-144	SnPb Dip	SnPb	
U34	TQFP-144	SnPb Dip	SnPb	
U48	TQFP-144	SnPb Dip	SnPb	
U57	TQFP-144	SnPb Dip	SnPb	
U12	TSOP-50	SnBi	SnPb	
U25	TSOP-50	SnBi	SnPb	
U29	TSOP-50	SnBi	SnPb	
U39	TSOP-50	SnBi	SnPb	
U61	TSOP-50	SnBi	SnPb	
U16	TSOP-50	SnPb	SnPb	
U24	TSOP-50	SnPb	SnPb	
U26	TSOP-50	SnPb	SnPb	
U40	TSOP-50	SnPb	SnPb	
U62	TSOP-50	SnPb	SnPb	

8.5.2 Assembly Details

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SnPb
  - Preheat = ~ 120 seconds @140-183°C
  - Solder joint peak temperature = 225°C
  - Time above reflow = 60-90 sec
  - Ramp Rate = 2-3 °C/sec

- Wave Soldering
- Location – BAE Systems Irving, Texas
- Wave Profile = SnPb
  - Solder Pot Temperature = 250°C
  - Preheat Board T = 101°C
  - Peak Temperature = 144°C
  - Speed: 110 cm/min

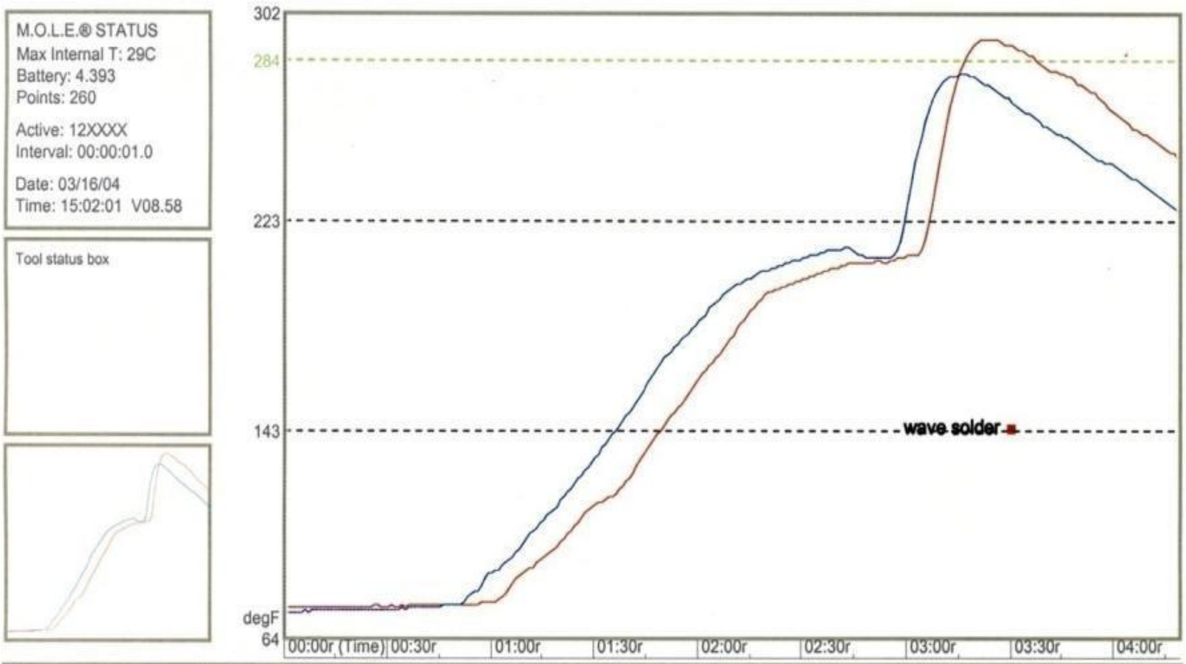


	Value	C1 = 00:01:24 r	C2 = 00:02:48 r	C3 = 00:04:12 r	C4 = 00:05:36 r	Units
▫	open					
▫	bad t/c					
▪	below U50 CSP center edge	119	159	192	174	degC
▫	trailing end U4/U55					
▫	open					
▫	open					

	T Above Ref	Low = 140	Med = 180	Hi = 183	Cure Factor	Units
▫	open					
▫	bad t/c					
▪	below U50 CSP center edge	00:04:32	00:01:37	00:01:32	0%	Time
▫	trailing end U4/U55					
▫	open					
▫	open					

	Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
▫	open							
▫	bad t/c							
▪	below U50 CSP center edge	23	00:00:00 r	228	00:05:00 r	143.9	56.1	degC
▫	trailing end U4/U55							
▫	open							
▫	open							

Figure 8 Reflow Oven Profile (SnPb)



Value	C1 = 00:00:51r	C2 = 00:01:42r	C3 = 00:02:33r	C4 = 00:03:24r	Units
t/x#1 trailing edge of pwb	77	130	202	292	degF
t/c#2 center of pwb	77	154	210	274	degF

T Above Ref	Low = 284	Med = 361	Hi = 446	Cure Factor	Units
t/x#1 trailing edge of pwb	00:00:21	00:00:00	00:00:00	0%	degF
t/c#2 center of pwb	00:00:00	00:00:00	00:00:00	0%	degF

Figure 9 Wave Solder Profile (SnPb)

8.6 SnPb Manufactured (Batch D)

8.6.1 Bare Boards

- 17 boards
- 14.5”X 9”X 0.09”
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag surface finish

Table 12 Test Vehicle Tracker – SnPb Manufactured Test Vehicles (Batch D)

Project Activity	Board Number	Board Finish
Extra Boards	SN2	Immersion Ag
Test Vehicle Characterization	SN4	
Vibration	SN15 – SN19	
Drop Testing	SN25 – SN29	
Mechanical Shock	SN30 – SN34	

Table 13 Component Finish Matrix – SnPb Manufactured Test Vehicles (Batch D)

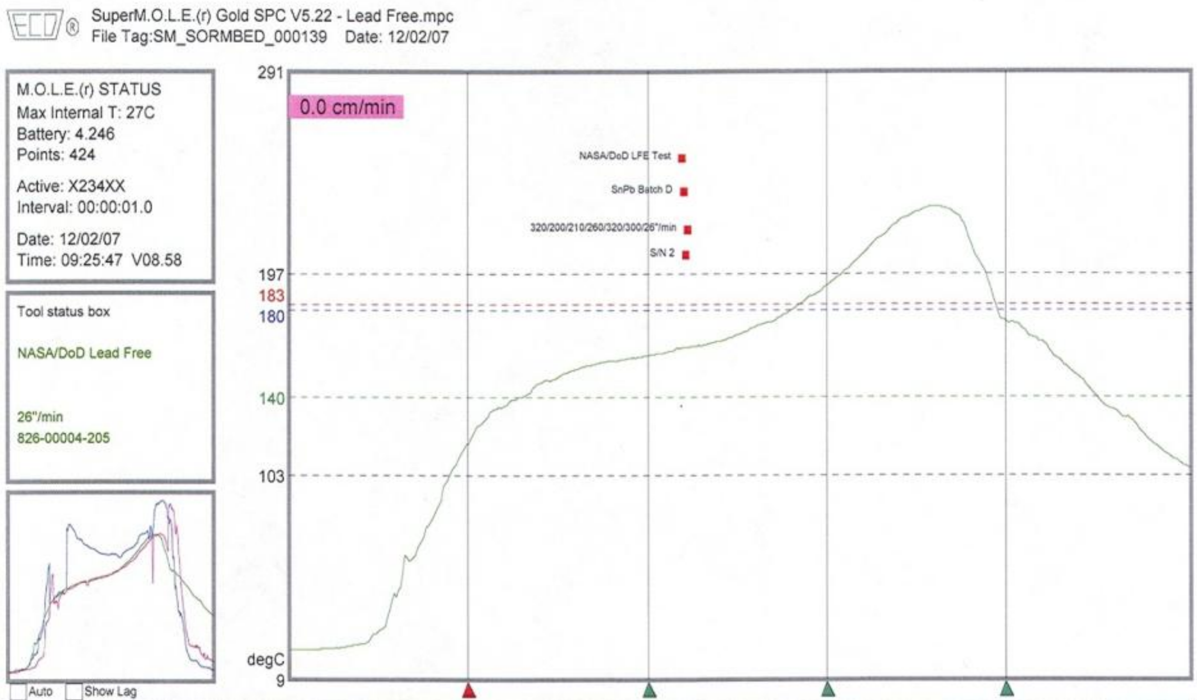
RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U18	BGA-225	SnPb	SnPb	
U43	BGA-225	SnPb	SnPb	
U04	BGA-225	SnPb	SnPb	
U06	BGA-225	SnPb	SnPb	
U55	BGA-225	SnPb	SnPb	
U02	BGA-225	SnPb	SnPb	
U05	BGA-225	SnPb	SnPb	
U21	BGA-225	SnPb	SnPb	
U44	BGA-225	SnPb	SnPb	
U56	BGA-225	SnPb	SnPb	
U09	CLCC-20	SnPb	SnPb	
U13	CLCC-20	SnPb	SnPb	
U22	CLCC-20	SnPb	SnPb	
U46	CLCC-20	SnPb	SnPb	
U53	CLCC-20	SnPb	SnPb	
U10	CLCC-20	SnPb	SnPb	
U14	CLCC-20	SnPb	SnPb	
U17	CLCC-20	SnPb	SnPb	
U45	CLCC-20	SnPb	SnPb	
U52	CLCC-20	SnPb	SnPb	
U32	CSP-100	SnPb	SnPb	
U33	CSP-100	SnPb	SnPb	
U35	CSP-100	SnPb	SnPb	
U50	CSP-100	SnPb	SnPb	
U63	CSP-100	SnPb	SnPb	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U19	CSP-100	SnPb	SnPb	
U36	CSP-100	SnPb	SnPb	
U37	CSP-100	SnPb	SnPb	
U42	CSP-100	SnPb	SnPb	
U60	CSP-100	SnPb	SnPb	
U08	PDIP-20	SnPb		SnPb
U23	PDIP-20	SnPb		SnPb
U49	PDIP-20	SnPb		SnPb
U59	PDIP-20	SnPb		SnPb
U30	PDIP-20	SnPb		SnPb
U38	PDIP-20	SnPb		SnPb
U11	PDIP-20	SnPb		SnPb
U51	PDIP-20	SnPb		SnPb
U15	QFN	SnPb	SnPb	
U27	QFN	SnPb	SnPb	
U28	QFN	SnPb	SnPb	
U47	QFN	SnPb	SnPb	
U54	QFN	SnPb	SnPb	
U01	TQFP-144	Matte Sn	SnPb	
U07	TQFP-144	Matte Sn	SnPb	
U20	TQFP-144	Matte Sn	SnPb	
U41	TQFP-144	Matte Sn	SnPb	
U58	TQFP-144	Matte Sn	SnPb	
U03	TQFP-144	Matte Sn	SnPb	
U31	TQFP-144	Matte Sn	SnPb	
U34	TQFP-144	Matte Sn	SnPb	
U48	TQFP-144	Matte Sn	SnPb	
U57	TQFP-144	Matte Sn	SnPb	
U12	TSOP-50	SnPb	SnPb	
U25	TSOP-50	SnPb	SnPb	
U29	TSOP-50	SnPb	SnPb	
U39	TSOP-50	SnPb	SnPb	
U61	TSOP-50	SnPb	SnPb	
U16	TSOP-50	SnPb	SnPb	
U24	TSOP-50	SnPb	SnPb	
U26	TSOP-50	SnPb	SnPb	
U40	TSOP-50	SnPb	SnPb	
U62	TSOP-50	SnPb	SnPb	

8.6.2 Assembly Details

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SnPb
  - Preheat = ~ 120 seconds @140-183°C
  - Solder joint peak temperature = 225°C
  - Time above reflow = 60-90 sec
  - Ramp Rate = 2-3 °C/sec

- Wave Soldering
- Location – BAE Systems Irving, Texas
- Wave Profile = SnPb
  - Solder Pot Temperature = 250°C
  - Preheat Board T = 101°C
  - Peak Temperature = 144°C
  - Speed: 110 cm/min



	Value	C1 = 00:01:24 r	C2 = 00:02:48 r	C3 = 00:04:12 r	C4 = 00:05:36 r	Units
▫	open					
▫	bad t/c					
▪	below U50 CSP center edge	119	159	192	174	degC
▫	trailing end U4/U55					
▫	open					
▫	open					

	T Above Ref	Low = 140	Med = 180	Hi = 183	Cure Factor	Units
▫	open					
▫	bad t/c					
▪	below U50 CSP center edge	00:04:32	00:01:37	00:01:32	0%	Time
▫	trailing end U4/U55					
▫	open					
▫	open					

	Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
▫	open							
▫	bad t/c							
▪	below U50 CSP center edge	23	00:00:00 r	228	00:05:00 r	143.9	56.1	degC
▫	trailing end U4/U55							
▫	open							
▫	open							

Figure 10 Reflow Oven Profile (SnPb)

Value	C1 = 00:00:51r	C2 = 00:01:42r	C3 = 00:02:33r	C4 = 00:03:24r	Units
t/x#1 trailing edge of pwb	77	130	202	292	degF
t/c#2 center of pwb	77	154	210	274	degF

T Above Ref	Low = 284	Med = 361	Hi = 446	Cure Factor	Units
t/x#1 trailing edge of pwb	00:00:21	00:00:00	00:00:00	0%	degF
t/c#2 center of pwb	00:00:00	00:00:00	00:00:00	0%	degF

Figure 11 Wave Solder Profile (SnPb)

8.7 Lead-Free Manufactured (Batch E)

8.7.1 Bare Boards

- 20 boards
- 14.5”X 9”X 0.09”
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag and ENIG surface finishes

Table 14 Test Vehicle Tracker – Lead-Free Manufactured Test Vehicles (Batch E)

Project Activity	Board Number	Board Finish	Board Number	Board Finish
Extra Boards	SN35	Immersion Ag	N/A	ENIG
Test Vehicle Characterization	SN39		SN93	
Thermal Cycling: -55C to +125C	SN41 – SN45		SN95	
Thermal Cycling: -20C to +80C	SN50 – SN54		N/A	
Combined Environments Testing	SN69 – SN73		SN97	

Table 15 Component Finish Matrix – Lead-Free Manufactured Test Vehicles (Batch E)

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U02	BGA-225	SAC405	SAC305	
U05	BGA-225	SAC405	SAC305	
U21	BGA-225	SAC405	SAC305	
U44	BGA-225	SAC405	SAC305	
U56	BGA-225	SAC405	SAC305	
U18	BGA-225	SnPb	SAC305	
U43	BGA-225	SnPb	SAC305	
U04	BGA-225	SnPb	SAC305	
U06	BGA-225	SnPb	SAC305	
U55	BGA-225	SnPb	SAC305	
U10	CLCC-20	SAC305	SAC305	
U14	CLCC-20	SAC305	SAC305	
U17	CLCC-20	SAC305	SAC305	
U45	CLCC-20	SAC305	SAC305	
U52	CLCC-20	SAC305	SAC305	
U09	CLCC-20	SnPb	SAC305	
U13	CLCC-20	SnPb	SAC305	
U22	CLCC-20	SnPb	SAC305	
U46	CLCC-20	SnPb	SAC305	
U53	CLCC-20	SnPb	SAC305	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U19	CSP-100	SAC105	SAC305	
U36	CSP-100	SAC105	SAC305	
U37	CSP-100	SAC105	SAC305	
U42	CSP-100	SAC105	SAC305	
U60	CSP-100	SAC105	SAC305	
U32	CSP-100	SnPb	SAC305	
U33	CSP-100	SnPb	SAC305	
U35	CSP-100	SnPb	SAC305	
U50	CSP-100	SnPb	SAC305	
U63	CSP-100	SnPb	SAC305	
U08	PDIP-20	NiPdAu		SN100C
U23	PDIP-20	NiPdAu		SN100C
U49	PDIP-20	NiPdAu		SN100C
U59	PDIP-20	NiPdAu		SN100C
U11	PDIP-20	Sn		SN100C
U30	PDIP-20	Sn		SN100C
U38	PDIP-20	Sn		SN100C
U51	PDIP-20	Sn		SN100C
U15	QFN	Matte Sn	SAC305	
U27	QFN	Matte Sn	SAC305	
U28	QFN	Matte Sn	SAC305	
U47	QFN	Matte Sn	SAC305	
U54	QFN	Matte Sn	SAC305	
U03	TQFP-144	Matte Sn	SAC305	
U31	TQFP-144	Matte Sn	SAC305	
U34	TQFP-144	Matte Sn	SAC305	
U48	TQFP-144	Matte Sn	SAC305	
U57	TQFP-144	Matte Sn	SAC305	
U01	TQFP-144	SnPb Dip	SAC305	
U07	TQFP-144	SnPb Dip	SAC305	
U20	TQFP-144	SnPb Dip	SAC305	
U41	TQFP-144	SnPb Dip	SAC305	
U58	TQFP-144	SnPb Dip	SAC305	
U16	TSOP-50	SnBi	SAC305	
U24	TSOP-50	SnBi	SAC305	
U26	TSOP-50	SnBi	SAC305	
U40	TSOP-50	SnBi	SAC305	
U62	TSOP-50	SnBi	SAC305	
U12	TSOP-50	SnPb	SAC305	
U25	TSOP-50	SnPb	SAC305	
U29	TSOP-50	SnPb	SAC305	
U39	TSOP-50	SnPb	SAC305	
U61	TSOP-50	SnPb	SAC305	

8.7.2 Assembly Note

Test vehicles from Batch E were assembled with PDIP components that did not have the correct component finishes. Table 16 shows the PDIP component finish alloy for Batch E following assembly. The column titled “Comp Finish” in the table shows what component finishes the PDIP components were supposed to be. Cells highlighted in red indicate an incorrect component finish, while cells highlighted in green indicate a correct component finish. For Batch E, project stakeholders decided that no action would be taken since thermal cycle data can be compared across the various component locations, component location is not critical when comparing like components. Test vehicles will be tested as indicated in Table 16.

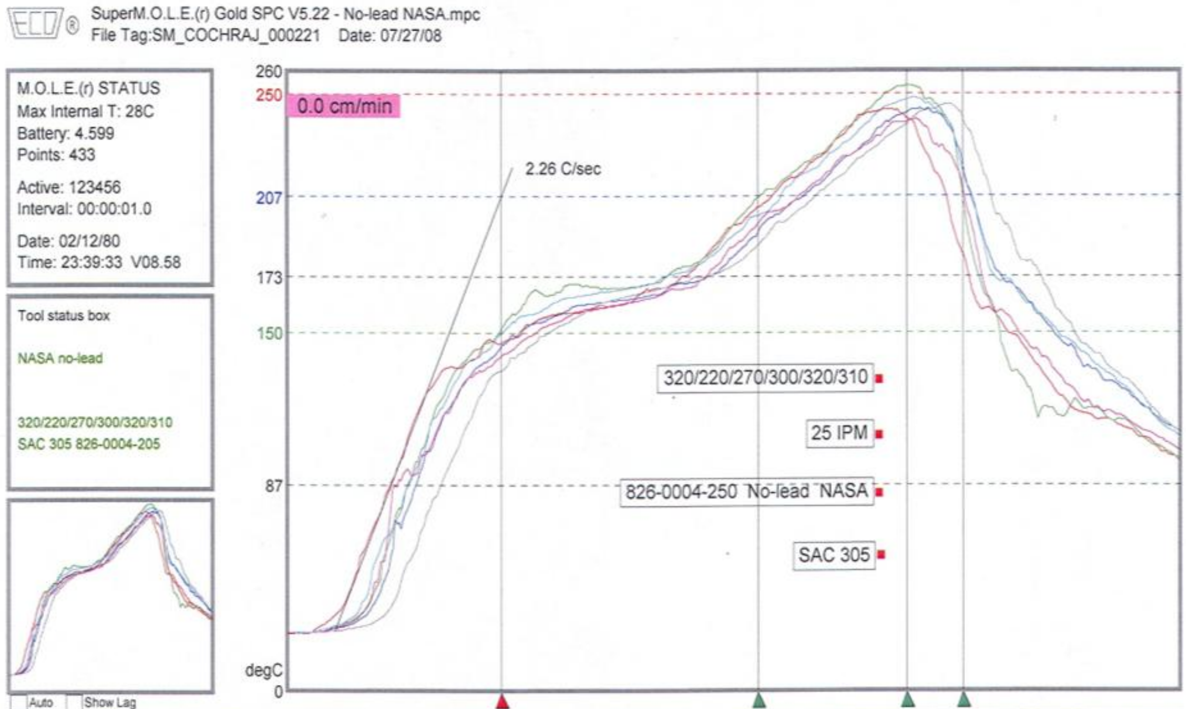
Table 16 PDIP Component Finishes – Lead-Free Manufactured Test Vehicles (Batch E)

BATCH E		Extra Board	Characterization		Thermal Cycle -55/+125C						Thermal Cycle -20/+80C					Combined Environmnets Test					
PDIP	Comp	35	39	93	41	42	43	44	45	95	50	51	52	53	54	69	70	71	72	73	97
Ref Desig	Finish																				
U8	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn
U23	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn
U49	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn
U59	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn
U11	Sn	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	Sn
U30	Sn	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	Sn
U38	Sn	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	Sn
U51	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn

8.7.3 Assembly Details

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SAC305
  - Preheat = 60-120 seconds @150-190°C
  - Peak temperature target = 243°C
  - Reflow:~20 seconds above 230°C
  - ~30-90 seconds above 220°C

- Wave Soldering
- Location – Scorpio Solutions
- Wave Profile = SN100C
  - Solder Pot Temperature = 265°C
  - Preheat Board T = 134°C
  - Peak Temperature = 157°C
  - Speed: 90 cm/min

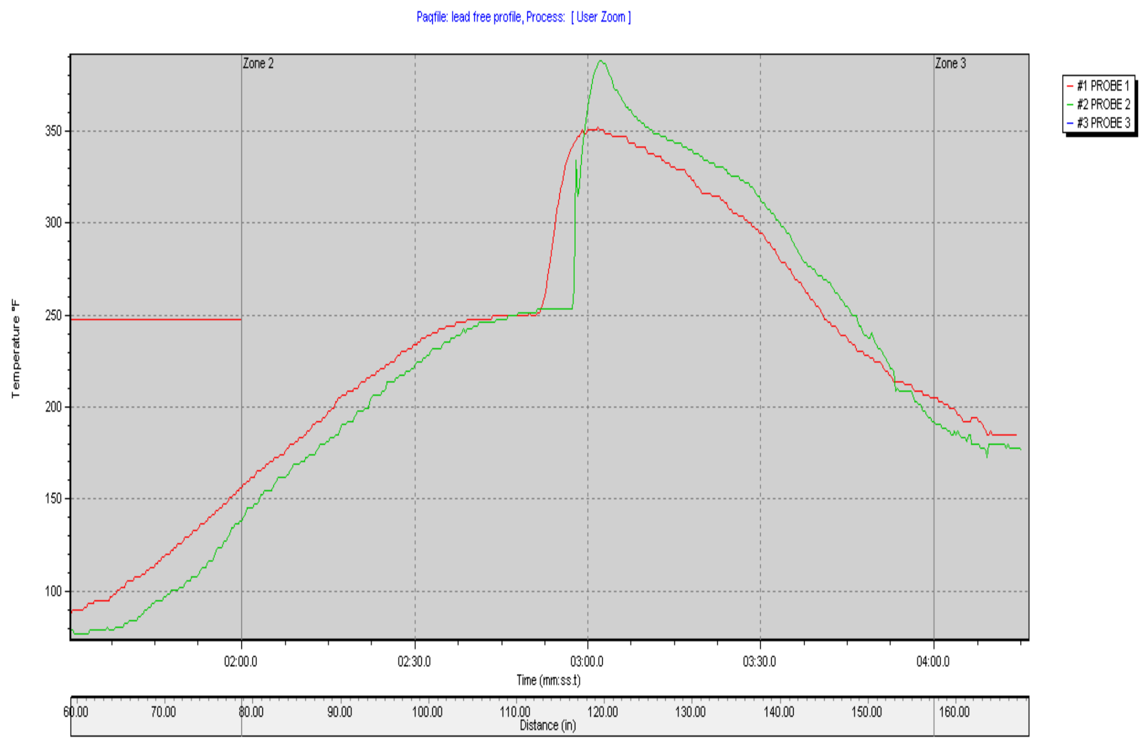


Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
South of U37 CSP	146	203	239	182	degC
North of U32 hybrid	144	193	242	218	degC
North of U42 CSP	151	207	253	204	degC
North of U4	140	196	238	209	degC
South of U58	149	199	248	216	degC
North of U36 CSP	134	187	237	238	degC

T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
North of U4	00:03:54	00:01:21	00:00:00	0%	Time
South of U58	00:04:29	00:01:33	00:00:00	0%	Time
North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Figure 12 Reflow Oven Profile – Lead-Free (SAC305)



Reflow Results

Probe	Positive Slope (°F/sec)	Positive Slope Time (mm:ss.t)	Time Above Liquidus (361.4°F) (mm:ss.t)	Peak Temperature (°F)	Delta T (°F)
#1 (°F)	12.98	02:54.6	00:00.0	352.4	36.0
#2 (°F)	18.46	02:58.5	00:07.8	388.4	
#3 (°F)	***	***	00:00.0	***	

Figure 13 Wave Solder Profile – Lead-Free (SN100C)

8.8 Lead-Free Manufactured (Batch F)

8.8.1 Bare Boards

- 43 boards
- 14.5"X 9"X 0.09"
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170°C
- Immersion Ag and ENIG surface finishes

Table 17 Test Vehicle Tracker – Lead-Free Manufactured Test Vehicles (Batch F)

Project Activity	Board Number	Board Finish	Board Number	Board Finish
Extra Boards	SN56	Immersion Ag	94	ENIG
Test Vehicle Characterization	SN58		N/A	
Vibration	SN36		96	
	SN40			
	SN74			
	SN76			
	SN78			
Drop Testing	SN55		N/A	
	SN59			
	SN57			
	SN92			
	SN77			
Mechanical Shock	SN88 – SN91		N/A	
	SN75			

*All test vehicles in Batch F were exposed to extended thermal aging, 4 days, per Section 12.0.

Table 18 Test Vehicle Tracker – Lead-Free Manufactured Test Vehicles [Crane Rework Effort] (Batch F)

Project Activity	Board Number	Board Finish
Extra Boards	SN37	Immersion Ag
Test Vehicle Characterization	N/A	
Thermal Cycling: -55C to +125C	SN38	
	SN46 – SN49	
Thermal Cycling: -20C to +80C	N/A	
Vibration	SN79	
	SN61 – SN68	
Combined Environments Testing	N/A	
Drop Testing	SN60	
	SN80 – SN87	
Mechanical Shock	N/A	

*All test vehicles in Batch F were exposed to extended thermal aging, 4 days, per Section 12.0.

Table 19 Component Finish Matrix – Lead-Free Manufactured Test Vehicles (Batch F)

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U18	BGA-225	SAC405	SAC305	
U43	BGA-225	SAC405	SAC305	
U04	BGA-225	SAC405	SAC305	
U06	BGA-225	SAC405	SAC305	
U55	BGA-225	SAC405	SAC305	
U02	BGA-225	SAC405	SAC305	
U05	BGA-225	SAC405	SAC305	
U21	BGA-225	SAC405	SAC305	
U44	BGA-225	SAC405	SAC305	
U56	BGA-225	SAC405	SAC305	
U09	CLCC-20	SAC305	SAC305	
U13	CLCC-20	SAC305	SAC305	
U22	CLCC-20	SAC305	SAC305	
U46	CLCC-20	SAC305	SAC305	
U53	CLCC-20	SAC305	SAC305	
U10	CLCC-20	SAC305	SAC305	
U14	CLCC-20	SAC305	SAC305	
U17	CLCC-20	SAC305	SAC305	
U45	CLCC-20	SAC305	SAC305	
U52	CLCC-20	SAC305	SAC305	
U32	CSP-100	SAC105	SAC305	
U33	CSP-100	SAC105	SAC305	
U35	CSP-100	SAC105	SAC305	
U50	CSP-100	SAC105	SAC305	
U63	CSP-100	SAC105	SAC305	
U19	CSP-100	SAC105	SAC305	
U36	CSP-100	SAC105	SAC305	
U37	CSP-100	SAC105	SAC305	
U42	CSP-100	SAC105	SAC305	
U60	CSP-100	SAC105	SAC305	
U08	PDIP-20	NiPdAu		SN100C
U23	PDIP-20	NiPdAu		SN100C
U49	PDIP-20	NiPdAu		SN100C
U59	PDIP-20	Sn		SN100C
U30	PDIP-20	Sn		SN100C
U38	PDIP-20	Sn		SN100C
U11	PDIP-20	Sn		SN100C
U51	PDIP-20	Sn		SN100C
U15	QFN	Matte Sn	SAC305	
U27	QFN	Matte Sn	SAC305	
U28	QFN	Matte Sn	SAC305	
U47	QFN	Matte Sn	SAC305	
U54	QFN	Matte Sn	SAC305	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U01	TQFP-144	Matte Sn	SAC305	
U07	TQFP-144	Matte Sn	SAC305	
U20	TQFP-144	Matte Sn	SAC305	
U41	TQFP-144	Matte Sn	SAC305	
U58	TQFP-144	Matte Sn	SAC305	
U03	TQFP-144	Matte Sn	SAC305	
U31	TQFP-144	Matte Sn	SAC305	
U34	TQFP-144	Matte Sn	SAC305	
U48	TQFP-144	Matte Sn	SAC305	
U57	TQFP-144	Matte Sn	SAC305	
U12	TSOP-50	Sn	SAC305	
U25	TSOP-50	Sn	SAC305	
U29	TSOP-50	Sn	SAC305	
U39	TSOP-50	Sn	SAC305	
U61	TSOP-50	Sn	SAC305	
U16	TSOP-50	SnBi	SAC305	
U24	TSOP-50	SnBi	SAC305	
U26	TSOP-50	SnBi	SAC305	
U40	TSOP-50	SnBi	SAC305	
U62	TSOP-50	SnBi	SAC305	

8.8.2 Assembly Note

Test vehicles from Batch F were assembled with PDIP components that did not have the correct component finishes. Table 20 shows the PDIP component finish alloy for Batch F following assembly. The column titled “Comp Finish” in the table shows what component finishes the PDIP components were supposed to be. Cells highlighted in red indicate an incorrect component finish, while cells highlighted in green indicate a correct component finish. This creates a difficult problem for analyzing vibration test data since the vibration environment at a given location on a test vehicle can be very different from the vibration environment at a different location on the same vehicle during the same test. This means that only identical components in identical locations on identical test vehicles can be directly compared. It also implies that the test solder must be used on one set of test vehicles and the control solder on a second set of test vehicles. In an attempt to get like component finishes in the same locations on the vibration test vehicles, some test vehicles in Batch F were rearranged, by serial number, within the columns labeled Vibration, Drop, Characterization and Extra (see Table 21).

Table 20 PDIP Component Finishes – Lead-Free Manufactured Test Vehicles (Batch F)

BATCH F		Extra	Characterization		Vibration						Drop					Mechanical Shock				
PDIP Ref Desig	Comp Finish	36	40	94	55	56	57	58	59	96	74	75	76	77	78	88	89	90	91	92
U8	NiPdAu	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn
U23	NiPdAu	Sn	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn
U49	NiPdAu	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	NiPdAu
U11	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn
U30	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn
U38	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn
U51	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu
U59	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu

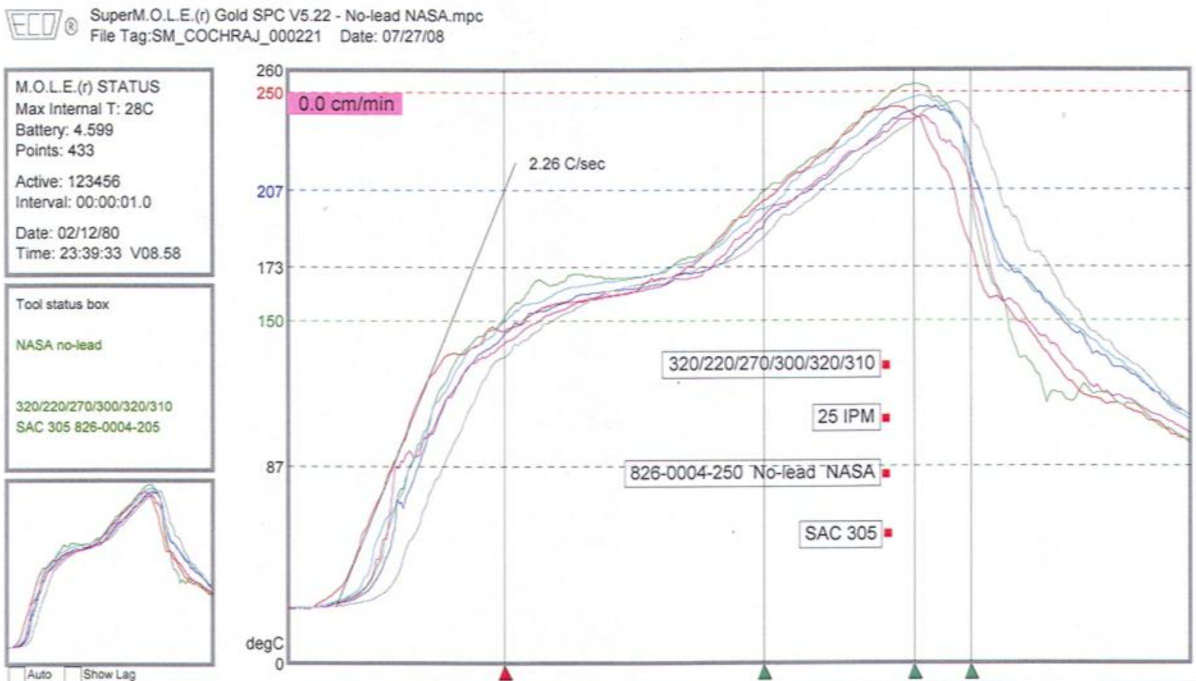
Table 21 PDIP Component Finishes – Lead-Free Manufactured Test Vehicles, Rearranged (Batch F)

BATCH F		Extra	Characterization		Vibration						Drop					Mechanical Shock				
PDIP	Comp	56	58	94	36	40	57	76	78	96	55	59	74	75	77	88	89	90	91	92
Ref Desig	Finish																			
U8	NiPdAu	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn
U23	NiPdAu	Sn	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn
U49	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	NiPdAu
U11	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn
U30	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn
U38	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	Sn
U51	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu
U59	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu	NiPdAu

8.8.3 Assembly Details

- Reflow Soldering
- Location – BAE Systems Irving, Texas
- Reflow Profile = SAC305:
  - Preheat = 60-120 seconds @150-190°C
  - Peak temperature target = 243°C
  - Reflow:~20 seconds above 230°C
  - ~30-90 seconds above 220°C

- Wave Soldering
- Location – Scorpio Solutions
- Wave Profile = SN100C:
  - Solder Pot Temperature = 265°C
  - Preheat Board T = 134°C
  - Peak Temperature = 157°C
  - Speed: 90 cm/min

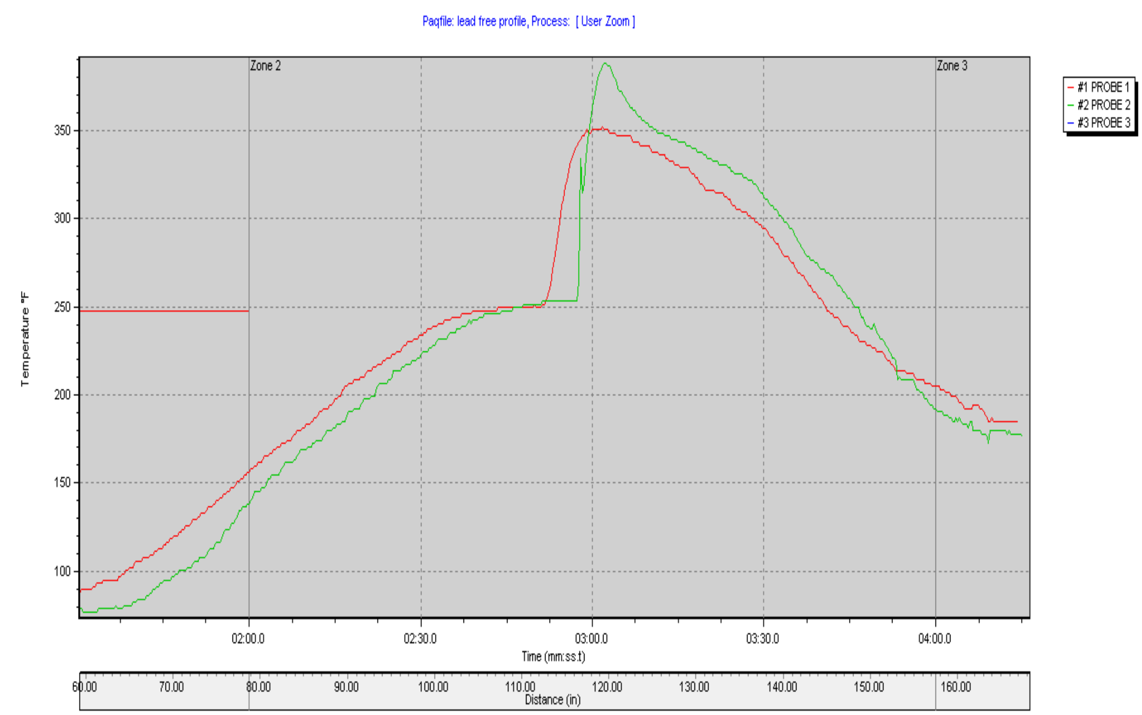


Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
South of U37 CSP	146	203	239	182	degC
North of U32 hybrid	144	193	242	218	degC
North of U42 CSP	151	207	253	204	degC
North of U4	140	196	238	209	degC
South of U58	149	199	248	216	degC
North of U36 CSP	134	187	237	238	degC

T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
North of U4	00:03:54	00:01:21	00:00:00	0%	Time
South of U58	00:04:29	00:01:33	00:00:00	0%	Time
North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Figure 14 Reflow Oven Profile – Lead-Free (SAC305)



Reflow Results

Probe	Positive Slope (°F/sec)	Positive Slope Time (mm:ss.t)	Time Above Liquidus (361.4°F) (mm:ss.t)	Peak Temperature (°F)	Delta T (°F)
#1 (°F)	12.98	02:54.6	00:00.0	352.4	36.0
#2 (°F)	18.46	02:58.5	00:07.8	388.4	
#3 (°F)	***	***	00:00.0	***	

Figure 15 Wave Solder Profile – Lead-Free (SN100C)

8.9 Lead-Free Manufactured (Batch G)

8.9.1 Bare Boards

- 11 boards
- 14.5”X 9”X 0.09”
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag surface finish

Table 22 Test Vehicle Tracker – Lead-Free Manufactured Test Vehicles (Batch G)

Project Activity	Board Number	Board Finish
Extra Boards	--	**Immersion Ag**
Test Vehicle Characterization	SN100	
Thermal Cycling: -55C to +125C	SN102 – SN106	
Thermal Cycling: -20C to +80C	--	
Combined Environments Testing	SN116 – SN120	

Table 23 Component Finish Matrix – Lead-Free Manufactured Test Vehicles (Batch G)

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U02	BGA-225	SAC405	SN100C	
U05	BGA-225	SAC405	SN100C	
U21	BGA-225	SAC405	SN100C	
U44	BGA-225	SAC405	SN100C	
U56	BGA-225	SAC405	SN100C	
U18	BGA-225	SnPb	SN100C	
U43	BGA-225	SnPb	SN100C	
U04	BGA-225	SnPb	SN100C	
U06	BGA-225	SnPb	SN100C	
U55	BGA-225	SnPb	SN100C	
U10	CLCC-20	SAC305	SN100C	
U14	CLCC-20	SAC305	SN100C	
U17	CLCC-20	SAC305	SN100C	
U45	CLCC-20	SAC305	SN100C	
U52	CLCC-20	SAC305	SN100C	
U09	CLCC-20	SnPb	SN100C	
U13	CLCC-20	SnPb	SN100C	
U22	CLCC-20	SnPb	SN100C	
U46	CLCC-20	SnPb	SN100C	
U53	CLCC-20	SnPb	SN100C	
U19	CSP-100	SAC105	SN100C	
U36	CSP-100	SAC105	SN100C	
U37	CSP-100	SAC105	SN100C	
U42	CSP-100	SAC105	SN100C	

RefDes	Component	Component Finish	Reflow Solder Alloy	Wave Solder Alloy
U60	CSP-100	SAC105	SN100C	
U32	CSP-100	SnPb	SN100C	
U33	CSP-100	SnPb	SN100C	
U35	CSP-100	SnPb	SN100C	
U50	CSP-100	SnPb	SN100C	
U63	CSP-100	SnPb	SN100C	
U08	PDIP-20	NiPdAu		SN100C
U23	PDIP-20	NiPdAu		SN100C
U49	PDIP-20	NiPdAu		SN100C
U59	PDIP-20	NiPdAu		SN100C
U11	PDIP-20	Sn		SN100C
U30	PDIP-20	Sn		SN100C
U38	PDIP-20	Sn		SN100C
U51	PDIP-20	Sn		SN100C
U15	QFN	Matte Sn	SN100C	
U27	QFN	Matte Sn	SN100C	
U28	QFN	Matte Sn	SN100C	
U47	QFN	Matte Sn	SN100C	
U54	QFN	Matte Sn	SN100C	
U03	TQFP-144	Matte Sn	SN100C	
U31	TQFP-144	Matte Sn	SN100C	
U34	TQFP-144	Matte Sn	SN100C	
U48	TQFP-144	Matte Sn	SN100C	
U57	TQFP-144	Matte Sn	SN100C	
U01	TQFP-144	SnPb Dip	SN100C	
U07	TQFP-144	SnPb Dip	SN100C	
U20	TQFP-144	SnPb Dip	SN100C	
U41	TQFP-144	SnPb Dip	SN100C	
U58	TQFP-144	SnPb Dip	SN100C	
U16	TSOP-50	SnBi	SN100C	
U24	TSOP-50	SnBi	SN100C	
U26	TSOP-50	SnBi	SN100C	
U40	TSOP-50	SnBi	SN100C	
U62	TSOP-50	SnBi	SN100C	
U12	TSOP-50	SnPb	SN100C	
U25	TSOP-50	SnPb	SN100C	
U29	TSOP-50	SnPb	SN100C	
U39	TSOP-50	SnPb	SN100C	
U61	TSOP-50	SnPb	SN100C	

8.9.2 Assembly Note

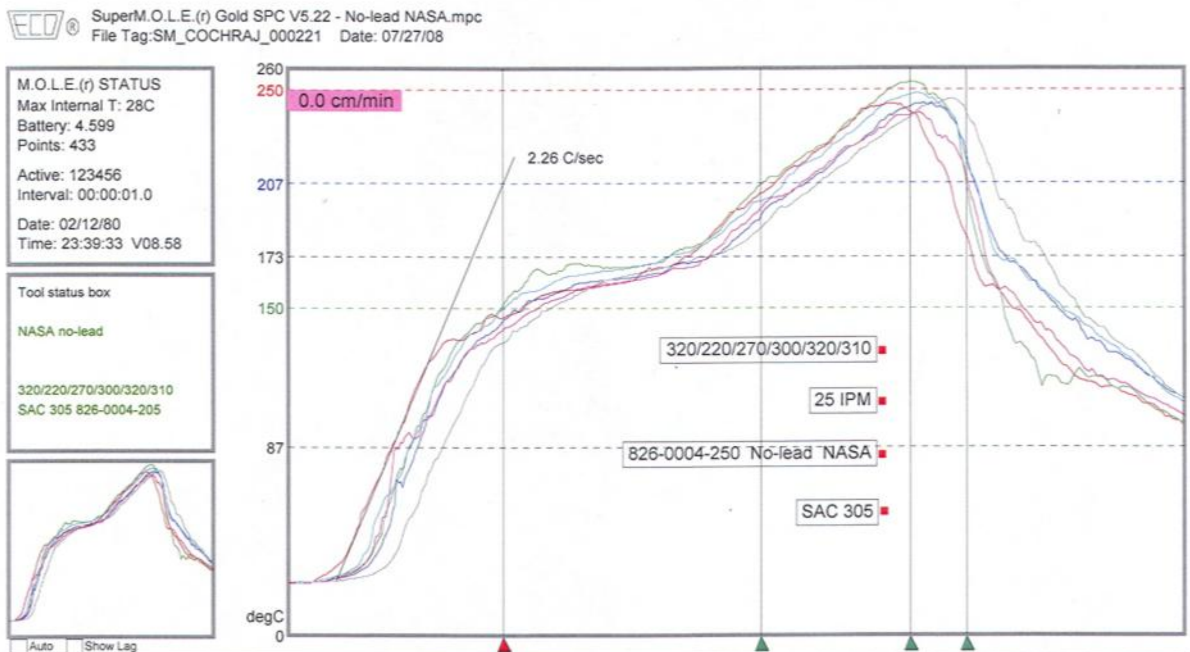
Test vehicles from Batch G were assembled with PDIP components that did not have the correct component finishes. Table 24 shows the PDIP component finish alloy for Batch G. The second column in the table shows what component finishes the PDIP components were supposed to be. Cells highlighted in red indicate an incorrect component finish, while cells highlighted in green indicate a correct component finish. For Batch G, no action was taken and the test vehicles will be tested as indicated in Table 24.

Table 24 PDIP Component Finishes – Lead-Free Manufactured Test Vehicles (Batch G)

BATCH G		Characterization	Thermal Cycle -55/+125					Combined Environments				
PDIP	Comp	100	102	103	104	105	106	116	117	118	119	120
Ref Desig	Finish											
U8	NiPdAu	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	NiPdAu	Sn	Sn	NiPdAu	Sn
U23	NiPdAu	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu
U49	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu
U59	NiPdAu	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu
U11	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu*
U30	Sn	NiPdAu	NiPdAu	Sn	Sn	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu
U38	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu
U51	Sn	NiPdAu	NiPdAu	Sn	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	Sn	NiPdAu

8.9.3 Assembly Details

- Reflow Profile = SN100C
- Location – BAE Systems Irving, Texas
  - Preheat = 60-120 seconds @150-190°C
  - Peak temperature target = 243°C
  - Reflow:~20 seconds above 230°C
  - ~30-90 seconds above 220°C
- Wave Profile = SN100C
- Location – Scorpio Solutions
  - Solder Pot Temperature = 265°C
  - Preheat Board T = 134°C
  - Peak Temperature = 157°C
  - Speed: 90 cm/min

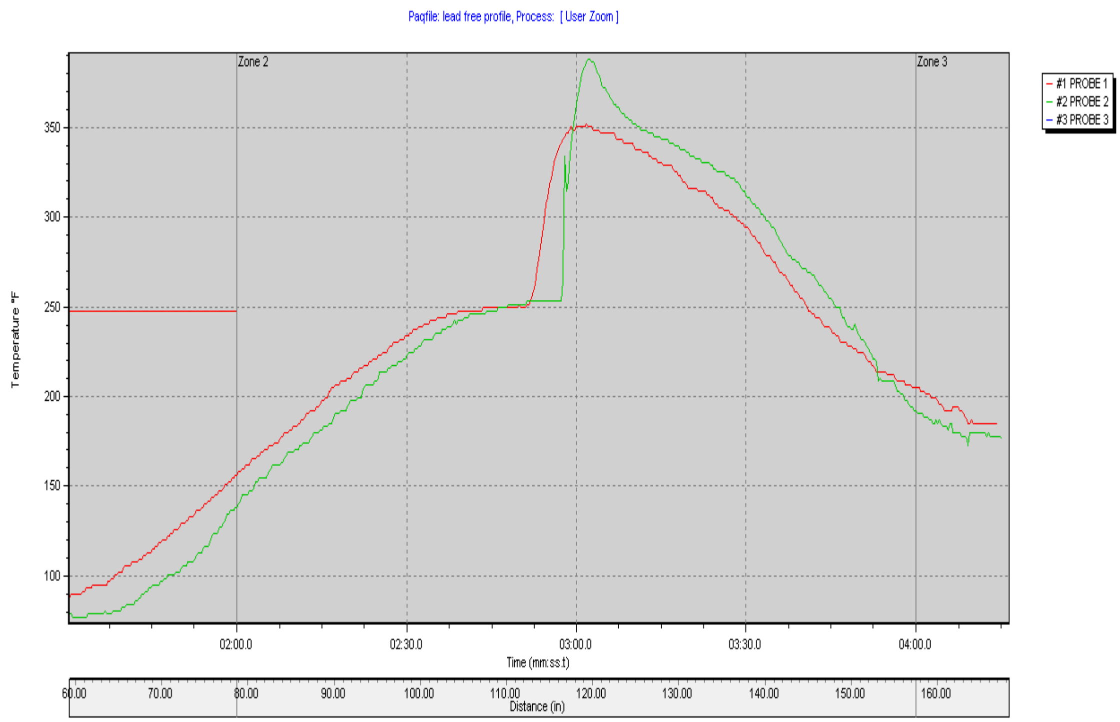


Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
South of U37 CSP	146	203	239	182	degC
North of U32 hybrid	144	193	242	218	degC
North of U42 CSP	151	207	253	204	degC
North of U4	140	196	238	209	degC
South of U58	149	199	248	216	degC
North of U36 CSP	134	187	237	238	degC

T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
North of U4	00:03:54	00:01:21	00:00:00	0%	Time
South of U58	00:04:29	00:01:33	00:00:00	0%	Time
North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Figure 16 Reflow Oven Profile – Lead-Free (SN100C)



Reflow Results

Probe	Positive Slope (°F/sec)	Positive Slope Time (mm:ss.t)	Time Above Liquidus (361.4°F) (mm:ss.t)	Peak Temperature (°F)	Delta T (°F)
#1 (°F)	12.98	02:54.6	00:00.0	352.4	36.0
#2 (°F)	18.46	02:58.5	00:07.8	388.4	
#3 (°F)	***	***	00:00.0	***	

Figure 17 Wave Solder Profile – Lead-Free (SN100C)

8.10 Lead-Free Manufactured (Batch H)

8.10.1 Bare Boards

- 6 boards
- 14.5”X 9”X 0.09”
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag surface finish

Table 25 Test Vehicle Tracker – Lead-Free Manufactured Test Vehicles (Batch H)

Project Activity	Board Number	Board Finish
Extra Boards	--	**Immersion Ag**
Test Vehicle Characterization	SN101	
Vibration	SN111 – SN115	
Drop Testing	--	
Mechanical Shock	--	

Table 26 Component Finish Matrix – Lead-Free Manufactured Test Vehicles (Batch H)

RefDes	Component	Component Finish	Reflow Solder	Wave Solder
U18	BGA-225	SAC405	SN100C	
U43	BGA-225	SAC405	SN100C	
U04	BGA-225	SAC405	SN100C	
U06	BGA-225	SAC405	SN100C	
U55	BGA-225	SAC405	SN100C	
U02	BGA-225	SAC405	SN100C	
U05	BGA-225	SAC405	SN100C	
U21	BGA-225	SAC405	SN100C	
U44	BGA-225	SAC405	SN100C	
U56	BGA-225	SAC405	SN100C	
U09	CLCC-20	SAC305	SN100C	
U13	CLCC-20	SAC305	SN100C	
U22	CLCC-20	SAC305	SN100C	
U46	CLCC-20	SAC305	SN100C	
U53	CLCC-20	SAC305	SN100C	
U10	CLCC-20	SAC305	SN100C	
U14	CLCC-20	SAC305	SN100C	
U17	CLCC-20	SAC305	SN100C	
U45	CLCC-20	SAC305	SN100C	
U52	CLCC-20	SAC305	SN100C	
U32	CSP-100	SAC105	SN100C	
U33	CSP-100	SAC105	SN100C	
U35	CSP-100	SAC105	SN100C	
U50	CSP-100	SAC105	SN100C	

RefDes	Component	Component Finish	Reflow Solder	Wave Solder
U63	CSP-100	SAC105	SN100C	
U19	CSP-100	SAC105	SN100C	
U36	CSP-100	SAC105	SN100C	
U37	CSP-100	SAC105	SN100C	
U42	CSP-100	SAC105	SN100C	
U60	CSP-100	SAC105	SN100C	
U08	PDIP-20	NiPdAu		SN100C
U23	PDIP-20	NiPdAu		SN100C
U49	PDIP-20	NiPdAu		SN100C
U59	PDIP-20	Sn		SN100C
U30	PDIP-20	Sn		SN100C
U38	PDIP-20	Sn		SN100C
U11	PDIP-20	Sn		SN100C
U51	PDIP-20	Sn		SN100C
U15	QFN	Matte Sn	SN100C	
U27	QFN	Matte Sn	SN100C	
U28	QFN	Matte Sn	SN100C	
U47	QFN	Matte Sn	SN100C	
U54	QFN	Matte Sn	SN100C	
U01	TQFP-144	Matte Sn	SN100C	
U07	TQFP-144	Matte Sn	SN100C	
U20	TQFP-144	Matte Sn	SN100C	
U41	TQFP-144	Matte Sn	SN100C	
U58	TQFP-144	Matte Sn	SN100C	
U03	TQFP-144	Matte Sn	SN100C	
U31	TQFP-144	Matte Sn	SN100C	
U34	TQFP-144	Matte Sn	SN100C	
U48	TQFP-144	Matte Sn	SN100C	
U57	TQFP-144	Matte Sn	SN100C	
U12	TSOP-50	Sn	SN100C	
U25	TSOP-50	Sn	SN100C	
U29	TSOP-50	Sn	SN100C	
U39	TSOP-50	Sn	SN100C	
U61	TSOP-50	Sn	SN100C	
U16	TSOP-50	SnBi	SN100C	
U24	TSOP-50	SnBi	SN100C	
U26	TSOP-50	SnBi	SN100C	
U40	TSOP-50	SnBi	SN100C	
U62	TSOP-50	SnBi	SN100C	

8.10.2 Assembly Note

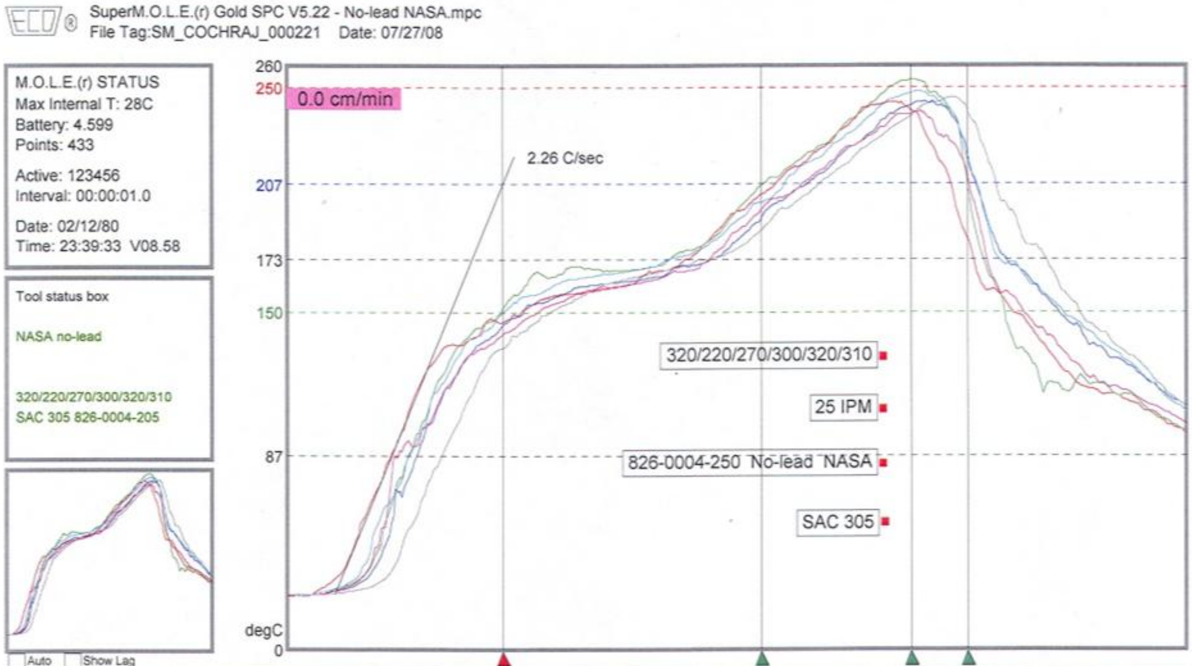
Test vehicles from Batch H were assembled with PDIP components that did not have the correct component finishes. Table 27 shows the PDIP component finish alloy for Batch H following asembly. The column titled "Comp Finish" in the table shows what component finishes the PDIP components were supposed to be. Cells highlighted in red indicate an incorrect component finish, while cells highlighted in green indicate a correct component finish. This creates a difficult problem for analyzing vibration test data since the vibration environment at a given location on a test vehicle can be very different from the vibration environment at a different location on the same vehicle during the same test. This means that only identical components in identical locations on identical test vehicles can be directly compared. It also implies that the test solder must be used on one set of test vehicles and the control solder on a second set of test vehicles. For Batch H, no action was taken due to a limited number of those particular test vehicles. Test vehicles will be tested as indicated in Table 27.

Table 27 PDIP Component Finishes – Lead-Free Manufactured Test Vehicles (Batch H)

BATCH H		Characterization	Vibration				
PDIP	Comp	101	111	112	113	114	115
Ref Desig	Finish						
U8	NiPdAu	Sn	Sn	NiPdAu	NiPdAu	Sn	NiPdAu
U23	NiPdAu	NiPdAu	Sn	NiPdAu	NiPdAu	Sn	NiPdAu
U49	NiPdAu	Sn	Sn	NiPdAu	Sn	Sn	Sn
U11	Sn	Sn	Sn	NiPdAu	NiPdAu	NiPdAu	NiPdAu
U30	Sn	NiPdAu	Sn	Sn	NiPdAu	Sn	NiPdAu
U38	Sn	NiPdAu	Sn	Sn	NiPdAu*	Sn	NiPdAu
U51	Sn	Sn	Sn	Sn	NiPdAu	Sn	Sn
U59	Sn	Sn	Sn	Sn	NiPdAu	Sn	Sn

8.10.3 Assembly Details

- Reflow Profile = SN100C
- Location – BAE Systems Irving, Texas
  - Preheat = 60-120 seconds @150-190°C
  - Peak temperature target = 243°C
  - Reflow:~20 seconds above 230°C
  - ~30-90 seconds above 220°C
- Wave Profile = SN100C
- Location – Scorpio Solutions
  - Solder Pot Temperature = 265°C
  - Preheat Board T = 134°C
  - Peak Temperature = 157°C
  - Speed: 90 cm/min

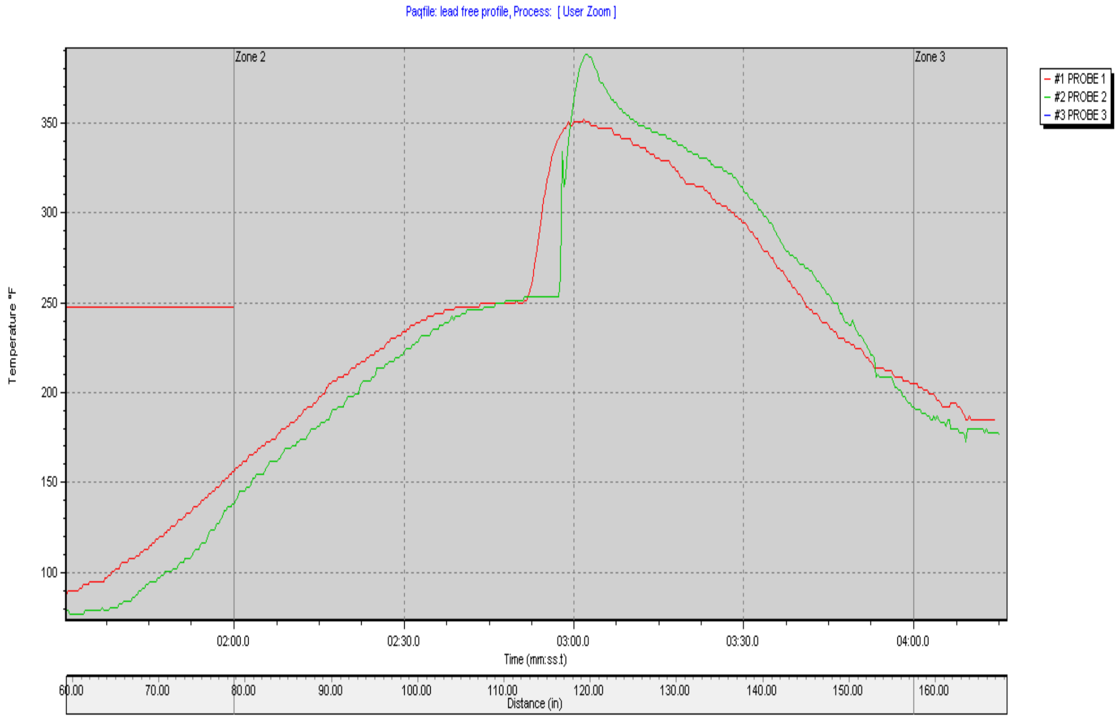


Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
South of U37 CSP	146	203	239	182	degC
North of U32 hybrid	144	193	242	218	degC
North of U42 CSP	151	207	253	204	degC
North of U4	140	196	238	209	degC
South of U58	149	199	248	216	degC
North of U36 CSP	134	187	237	238	degC

T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
North of U4	00:03:54	00:01:21	00:00:00	0%	Time
South of U58	00:04:29	00:01:33	00:00:00	0%	Time
North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Figure 18 Reflow Oven Profile – Lead-Free (SN100C)



Reflow Results

Probe	Positive Slope (°F/sec)	Positive Slope Time (mm:ss.t)	Time Above Liquidus (361.4°F) (mm:ss.t)	Peak Temperature (°F)	Delta T (°F)
#1 (°F)	12.98	02:54.6	00:00.0	352.4	36.0
#2 (°F)	18.46	02:58.5	00:07.8	388.4	
#3 (°F)	***	***	00:00.0	***	

Figure 19 Wave Solder Profile – Lead-Free (SN100C)

8.11 Lead-Free Manufactured (Batch I)

8.11.1 Bare Boards

- 6 boards
- 14.5"X 9"X 0.09"
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170ºC
- Immersion Ag surface finish

Table 28 Test Vehicle Tracker – Lead-Free Manufactured Test Vehicles (Batch I)

Project Activity	Board Number	Board Finish
Extra Boards	SN98 – SN99	Immersion Ag
Test Vehicle Characterization	--	
Thermal Cycling: -55C to +125C	SN107 – SN110	
Thermal Cycling: -20C to +80C	--	
Vibration	--	
Combined Environments Testing	--	
Drop Testing	--	
Mechanical Shock	--	

*All test vehicles in Batch I were exposed to extended thermal aging, 4 days, per Section 12.0.

Table 29 Component Finish Matrix – Lead-Free Manufactured Test Vehicles (Batch I)

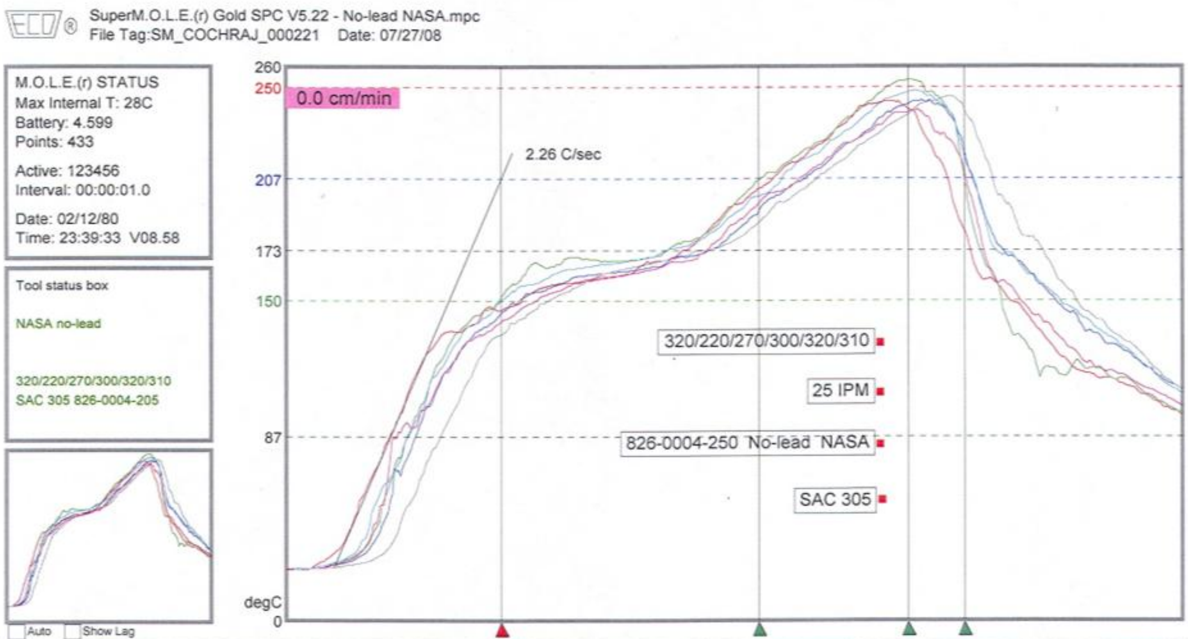
RefDes	Component	Component Finish	Reflow Solder	Wave Solder
U18	BGA-225	SAC405	SN100C	
U43	BGA-225	SAC405	SN100C	
U04	BGA-225	SAC405	SN100C	
U06	BGA-225	SAC405	SN100C	
U55	BGA-225	SAC405	SN100C	
U02	BGA-225	SAC405	SN100C	
U05	BGA-225	SAC405	SN100C	
U21	BGA-225	SAC405	SN100C	
U44	BGA-225	SAC405	SN100C	
U56	BGA-225	SAC405	SN100C	
U09	CLCC-20	SAC305	SN100C	
U13	CLCC-20	SAC305	SN100C	
U22	CLCC-20	SAC305	SN100C	
U46	CLCC-20	SAC305	SN100C	
U53	CLCC-20	SAC305	SN100C	
U10	CLCC-20	SAC305	SN100C	
U14	CLCC-20	SAC305	SN100C	
U17	CLCC-20	SAC305	SN100C	
U45	CLCC-20	SAC305	SN100C	
U52	CLCC-20	SAC305	SN100C	

RefDes	Component	Component Finish	Reflow Solder	Wave Solder
U32	CSP-100	SN100C	SN100C	
U33	CSP-100	SN100C	SN100C	
U35	CSP-100	SN100C	SN100C	
U50	CSP-100	SN100C	SN100C	
U63	CSP-100	SN100C	SN100C	
U19	CSP-100	SN100C	SN100C	
U36	CSP-100	SN100C	SN100C	
U37	CSP-100	SN100C	SN100C	
U42	CSP-100	SN100C	SN100C	
U60	CSP-100	SN100C	SN100C	
U08	PDIP-20	NiPdAu		SN100C
U23	PDIP-20	NiPdAu		SN100C
U49	PDIP-20	NiPdAu		SN100C
U59	PDIP-20	Sn		SN100C
U30	PDIP-20	Sn		SN100C
U38	PDIP-20	Sn		SN100C
U11	PDIP-20	Sn		SN100C
U51	PDIP-20	Sn		SN100C
U15	QFN	Matte Sn	SN100C	
U27	QFN	Matte Sn	SN100C	
U28	QFN	Matte Sn	SN100C	
U47	QFN	Matte Sn	SN100C	
U54	QFN	Matte Sn	SN100C	
U01	TQFP-144	Matte Sn	SN100C	
U07	TQFP-144	Matte Sn	SN100C	
U20	TQFP-144	Matte Sn	SN100C	
U41	TQFP-144	Matte Sn	SN100C	
U58	TQFP-144	Matte Sn	SN100C	
U03	TQFP-144	Matte Sn	SN100C	
U31	TQFP-144	Matte Sn	SN100C	
U34	TQFP-144	Matte Sn	SN100C	
U48	TQFP-144	Matte Sn	SN100C	
U57	TQFP-144	Matte Sn	SN100C	
U12	TSOP-50	Sn	SN100C	
U25	TSOP-50	Sn	SN100C	
U29	TSOP-50	Sn	SN100C	
U39	TSOP-50	Sn	SN100C	
U61	TSOP-50	Sn	SN100C	
U16	TSOP-50	SnBi	SN100C	
U24	TSOP-50	SnBi	SN100C	
U26	TSOP-50	SnBi	SN100C	
U40	TSOP-50	SnBi	SN100C	
U62	TSOP-50	SnBi	SN100C	

For Batch I only, the CSP components were re-balled by Premier Semiconductor Services. The original solder ball alloy was SAC105, Premier Semiconductor Services re-balled the components using SN100C solder balls.

8.11.2 Assembly Details

- Reflow Profile = SN100C
- Location – BAE Systems Irving, Texas
  - Preheat = 60-120 seconds @150-190°C
  - Peak temperature target = 243°C
  - Reflow:~20 seconds above 230°C
  - ~30-90 seconds above 220°C
- Wave Profile = SN100C
- Location – Scorpio Solutions
  - Solder Pot Temperature = 265°C
  - Preheat Board T = 134°C
  - Peak Temperature = 157°C
  - Speed: 90 cm/min

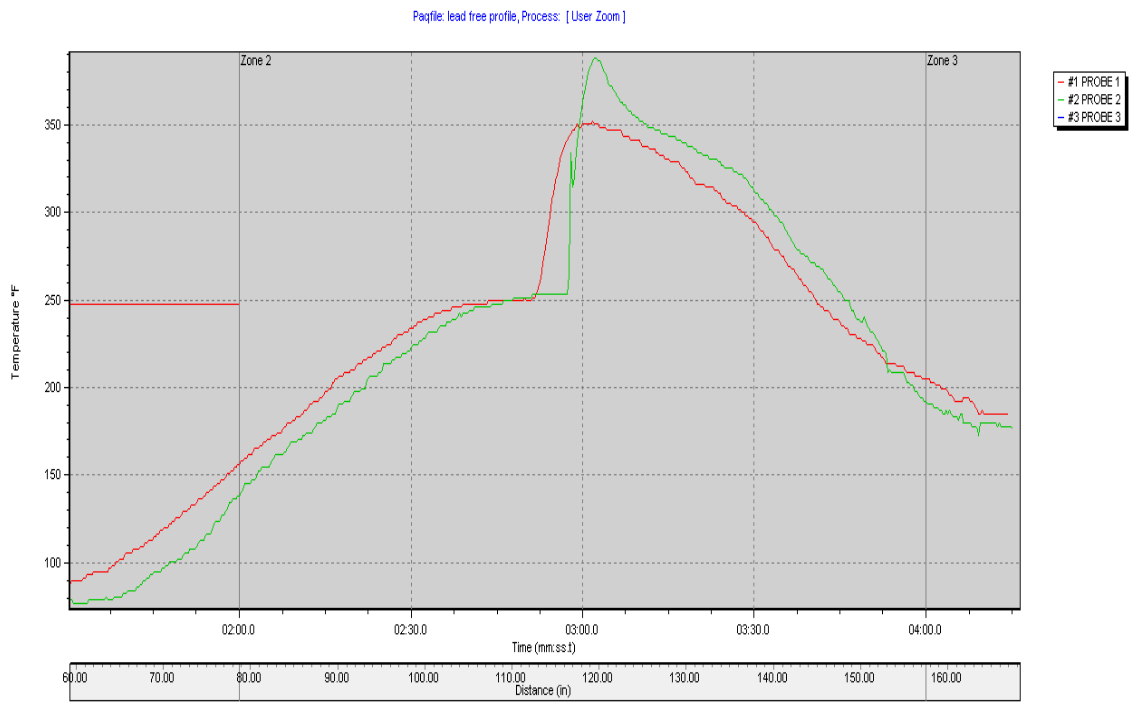


	Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
-	South of U37 CSP	146	203	239	182	degC
-	North of U32 hybrid	144	193	242	218	degC
-	North of U42 CSP	151	207	253	204	degC
-	North of U4	140	196	238	209	degC
-	South of U58	149	199	248	216	degC
-	North of U36 CSP	134	187	237	238	degC

	T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
-	South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
-	North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
-	North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
-	North of U4	00:03:54	00:01:21	00:00:00	0%	Time
-	South of U58	00:04:29	00:01:33	00:00:00	0%	Time
-	North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

	Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
-	South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
-	North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
-	North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
-	North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
-	South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
-	North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Figure 20 Example Reflow Oven Profile – Lead-Free (SN100C)



Reflow Results

Probe	Positive Slope (°F/sec)	Positive Slope Time (mm:ss.t)	Time Above Liquidus (361.4°F) (mm:ss.t)	Peak Temperature (°F)	Delta T (°F)
#1 (°F)	12.98	02:54.6	00:00.0	352.4	36.0
#2 (°F)	18.46	02:58.5	00:07.8	388.4	
#3 (°F)	***	***	00:00.0	***	

Figure 21 Example Wave Solder Profile – Lead-Free (SN100C)

9.0 Area Array X-Ray Analysis

Once test vehicle assembly is completed, all test vehicles were shipped to Lockheed Martin for x-ray analysis of the area array components, BGA and CSP. The QFN components were also analyzed. Percentages of voiding as well as ball shape were documented. Appendix F provides the details for the x-ray analysis.

10.0 Manufactured Test Vehicle Characterization

Rockwell Collins will cross-section the manufactured test vehicles set aside for characterization. A minimum of 1 component from each component type will be cross sectioned.

Table 30 Manufactured Test Vehicles for Characterization

Project Activity	Batch / Board Number
Test Vehicle Characterization	Batch A / SN161
	Batch B / SN123
	Batch B / SN154
	Batch C / SN3
	Batch E / SN39
	Batch E / SN93
	Batch G / SN100

11.0 Rework Protocol

There was a large volume of rework for this project. In order to get the rework procedures completed in a timely manner, multiple facilities performed the rework activities. The following tables shows which test vehicles went to which facilities for rework:

Table 31 Rework Test Vehicles for BAE Systems

Project Activity	Batch / Board Number
Extra Boards	Batch A / SN162
	Batch A / SN179
	Batch B / SN121
	Batch B / SN122
Test Vehicle Characterization	Batch A / SN161
	Batch B / SN123
	Batch B / SN154
Vibration	Batch A / SN174
	Batch A / SN175
	Batch A / SN176
	Batch A / SN177
	Batch A / SN178
	Batch B / SN134
	Batch B / SN135
	Batch B / SN136
	Batch B / SN137
	Batch B / SN138
	Batch B / SN157
Combined Environments Testing	Batch A / SN163
	Batch A / SN180
	Batch A / SN181
	Batch A / SN182
	Batch A / SN183
	Batch B / SN139
	Batch B / SN140
	Batch B / SN141
	Batch B / SN142
	Batch B / SN143
	Batch B / SN158

Table 32 Rework Test Vehicles for Lockheed Martin

Project Activity	Batch / Board Number
Thermal Cycling: -55C to +125C	Batch A / SN164
	Batch A / SN165
	Batch A / SN166
	Batch A / SN167
	Batch A / SN168
	Batch B / SN124
	Batch B / SN125
	Batch B / SN126
	Batch B / SN127
	Batch B / SN128
	Batch B / SN155
Thermal Cycling: -20C to +80C	Batch A / SN169
	Batch A / SN170
	Batch A / SN171
	Batch A / SN172
	Batch A / SN173
	Batch B / SN129
	Batch B / SN130
	Batch B / SN131
	Batch B / SN132
	Batch B / SN133
	Batch B / SN156

Table 33 Rework Test Vehicles for Rockwell Collins

Project Activity	Batch / Board Number
Drop Testing	Batch A / SN184
	Batch A / SN185
	Batch A / SN186
	Batch A / SN187
	Batch A / SN188
	Batch B / SN144
	Batch B / SN145
	Batch B / SN146
	Batch B / SN147
	Batch B / SN148
	Batch B / SN159
Mechanical Shock	Batch A / SN189
	Batch A / SN190
	Batch A / SN191
	Batch A / SN192
	Batch A / SN193
	Batch B / SN149
	Batch B / SN150
	Batch B / SN151
	Batch B / SN152
	Batch B / SN153
	Batch B / SN160

Table 34 Component Finish Matrix – Lead-Free Rework (Batch A)

RefDes	Component	Original Component Finish	Reflow Solder	Wave Solder	New Component Finish	Rework Solder	Rework Profile
U18	BGA-225	SAC405	SAC305		SAC405	SnPb	Lead-Free
U43	BGA-225	SAC405	SAC305		SAC405	SnPb	
U06	BGA-225	SAC405	SAC305		SAC405	SnPb	
U02	BGA-225	SAC405	SAC305		SAC405	Flux Only	
U21	BGA-225	SAC405	SAC305		SAC405	Flux Only	
U56	BGA-225	SAC405	SAC305		SAC405	Flux Only	
U33	CSP-100	SAC105	SAC305		SAC105	SnPb	
U50	CSP-100	SAC105	SAC305		SAC105	Flux Only	
U19	CSP-100	SAC105	SAC305		SAC105	Flux Only	
U37	CSP-100	SAC105	SAC305		SAC105	Flux Only	
U42	CSP-100	SAC105	SAC305		SAC105	SnPb	
U60	CSP-100	SAC105	SAC305		SAC105	SnPb	
U11	PDIP-20	Sn		SN100C	Sn	SN100C	
U51	PDIP-20	Sn		SN100C	Sn	SN100C	
U12	TSOP-50	Sn	SAC305		Sn	SnPb	
U25	TSOP-50	Sn	SAC305		Sn	SnPb	
U24	TSOP-50	SnBi	SAC305		SnBi	SAC305	
U26	TSOP-50	SnBi	SAC305		SnBi	SAC305	

Table 35 Component Finish Matrix – SnPb Rework (Batch B)

RefDes	Component	Original Component Finish	Reflow Solder	Wave Solder	New Component Finish	Rework Solder	Rework Profile
U18	BGA-225	SnPb	SnPb		SAC405	SnPb	SnPb
U43	BGA-225	SnPb	SnPb		SAC405	SnPb	
U06	BGA-225	SnPb	SnPb		SAC405	SnPb	
U02	BGA-225	SnPb	SnPb		SnPb	Flux Only	
U21	BGA-225	SnPb	SnPb		SnPb	Flux Only	
U56	BGA-225	SnPb	SnPb		SnPb	Flux Only	
U33	CSP-100	SnPb	SnPb		SAC105	SnPb	
U50	CSP-100	SnPb	SnPb		SnPb	Flux Only	
U19	CSP-100	SnPb	SnPb		SnPb	Flux Only	
U37	CSP-100	SnPb	SnPb		SnPb	Flux Only	
U42	CSP-100	SnPb	SnPb		SAC105	SnPb	
U60	CSP-100	SnPb	SnPb		SAC105	SnPb	
U11	PDIP-20	SnPb		SnPb	Sn	SnPb	
U51	PDIP-20	SnPb		SnPb	Sn	SnPb	
U12	TSOP-50	SnPb	SnPb		SnPb	SnPb	
U25	TSOP-50	SnPb	SnPb		SnPb	SnPb	
U24	TSOP-50	SnPb	SnPb		Sn	SnPb	
U26	TSOP-50	SnPb	SnPb		Sn	SnPb	

Components reworked were grouped by rework solder alloy / material (SnPb, Flux only, SAC305 and SN100C). The location performing the rework chose what order to rework the solder alloy / material groups, but had to use the numbered order below for specific component locations within the solder alloy / material group. When reworking a component, the component was to be removed and replaced before moving to the next component.

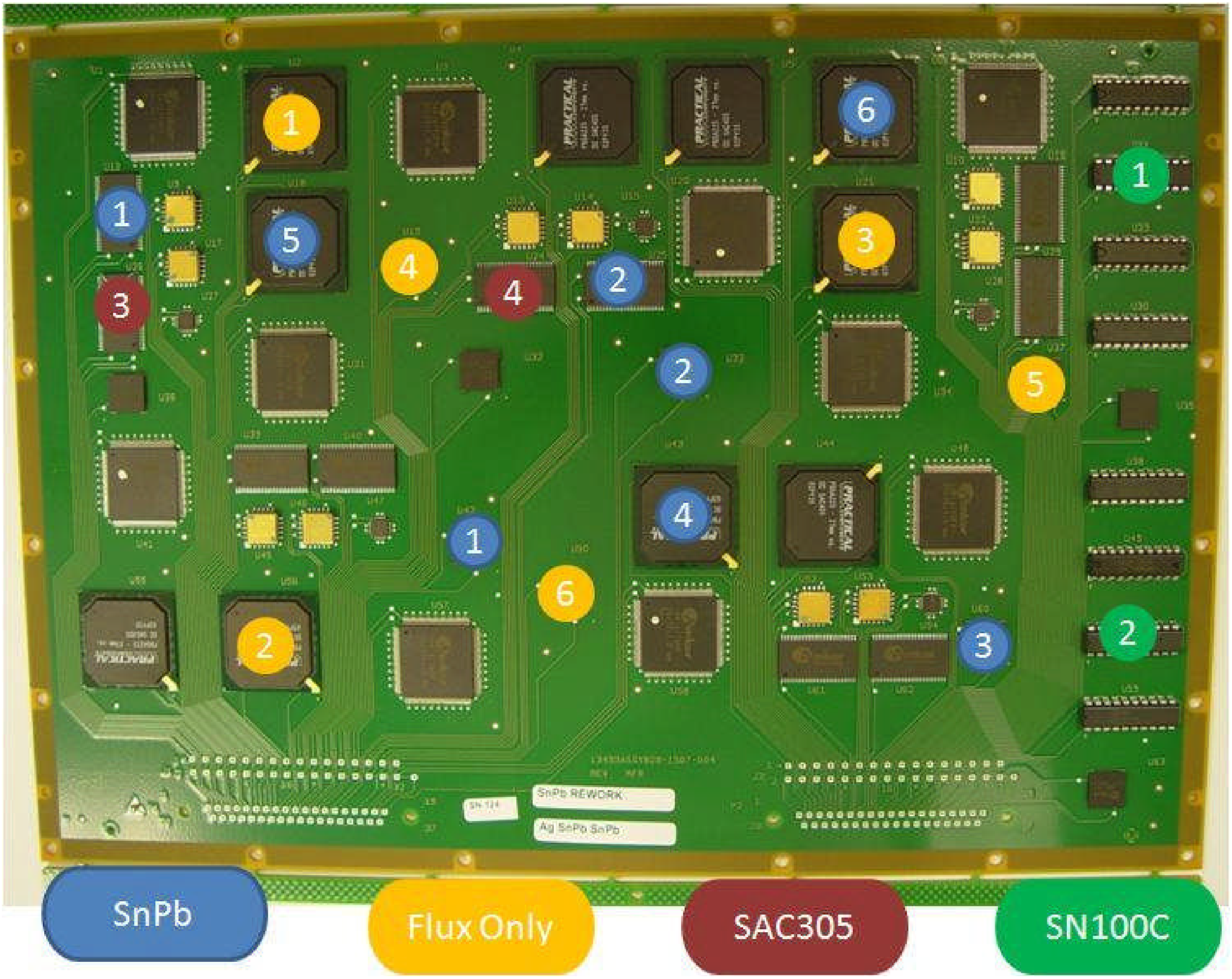
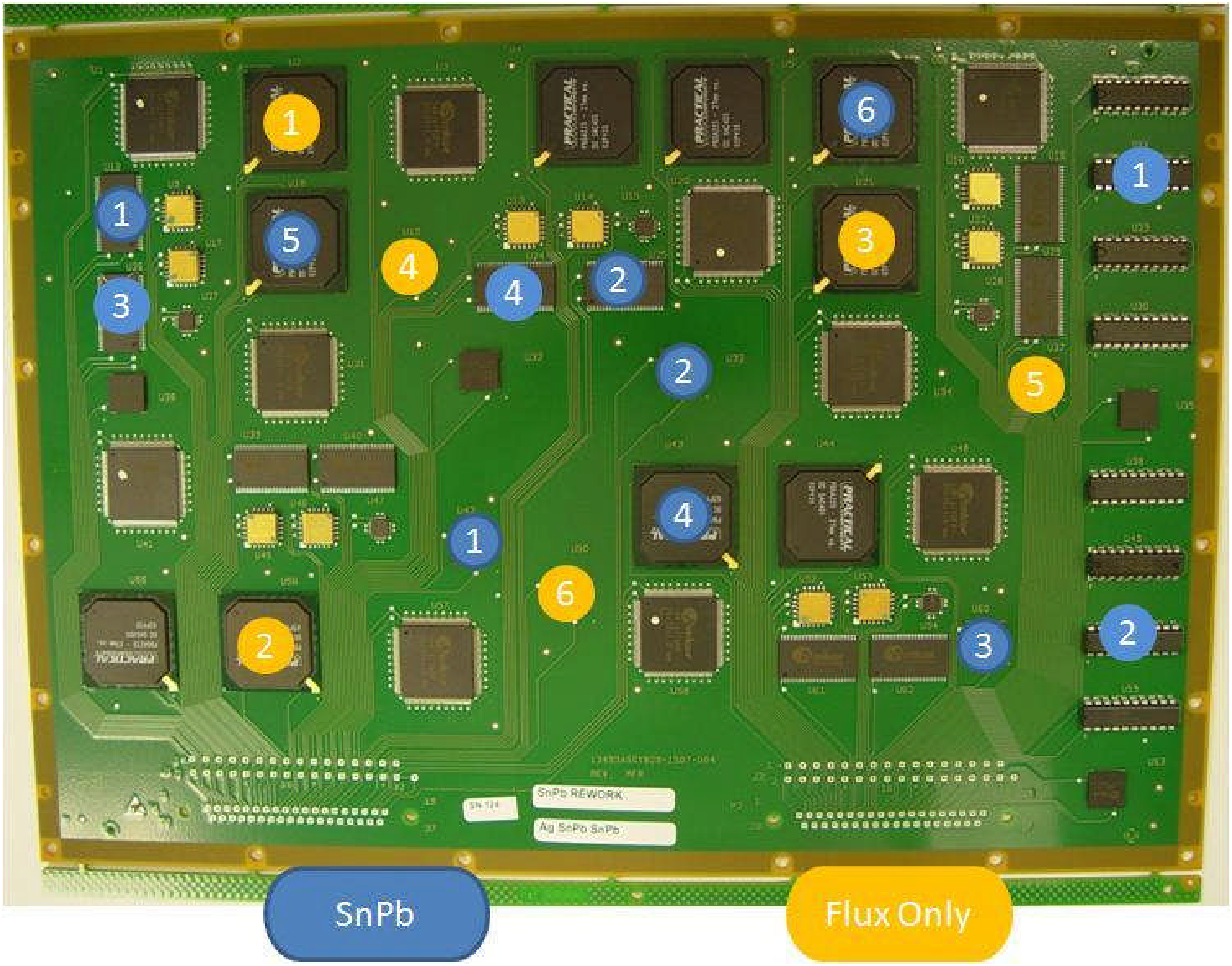


Figure 22 Rework Order – Batch A



[Figure 23](#) **Rework Order – Batch B**

NOTE:

- Contamination: Please note that care needs to be taken not to contaminate the rework station being used for SnPb and lead-free rework procedures. Cross contamination can cause decreased reliability of solder interconnects.
- Flux: In any solder removal/replacement sequence, use of external flux (ROLO) is allowed.
- Repair: If needed, repairs can be made during rework. Each location will document any repairs needed.
- BGA rework: Solder paste will be applied to the BGA not the board.
- CSP rework: Solder paste will be applied to the CSP not the board.
- Rework Sequence: For all component types:
    - Remove component
    - Cool
    - Replace

11.1 Component Preparation

11.1.1 Moisture bake out per J-STD-033, table 4-1

- Prior to rework, bake the components for 48 hours @ 125^{o}C

11.2 Rework Procedure per IPC-7711

11.2.1 Moisture bake out

- Prior to rework, bake boards for 4 hours @ 230^{o}F and store in a dry environment until all rework is complete.

11.2.2 Cleaning

- In-line clean after rework (wash within shift), document multiple cleanings on traveler
- Clean as required per J-STD-001
- Document cleaning chemistry per rework location

11.2.3 Removal and Replacement

11.2.3.1 Removal of Leaded Through Hole Parts

- Remove components per IPC-7711 method 3.1.1

11.2.3.2 Replacement of Leaded Through Hole Parts

- Per J-STD 001 certified soldering
- Use Metcal STTC-138, 700^{o}F tips and rosin base flux

11.2.3.3 Removal and Replacement of Leaded Surface Mount Devices

- Remove using solder wick and replace per J-STD 001
- Hand procedure per IPC 7711
  - Remove by using soldering iron method by removing excess solder using solder braid (wick). Heat and lift each lead from the pad surface using a dental pick or similar device.

11.2.3.4 Replacement of Leaded Surface Mount Devices

- Per J-STD 001 certified soldering
- Use Metcal STTC-125 or STTC-142, 700^{o}F tips and rosin base flux

11.2.3.5 Removal and Replacement of area array components

- Removal per procedure IPC-7711 - 3.9.1
- Replace per procedure IPC-7711 - 5.7.2; use paste / tacky flux
- Thermal couple map
- Drill center and polarity corner to place thermal couple in every BGA, name profile using ref designator for SnPb and lead-free
  - o .032"drill bit with a .090" depth.

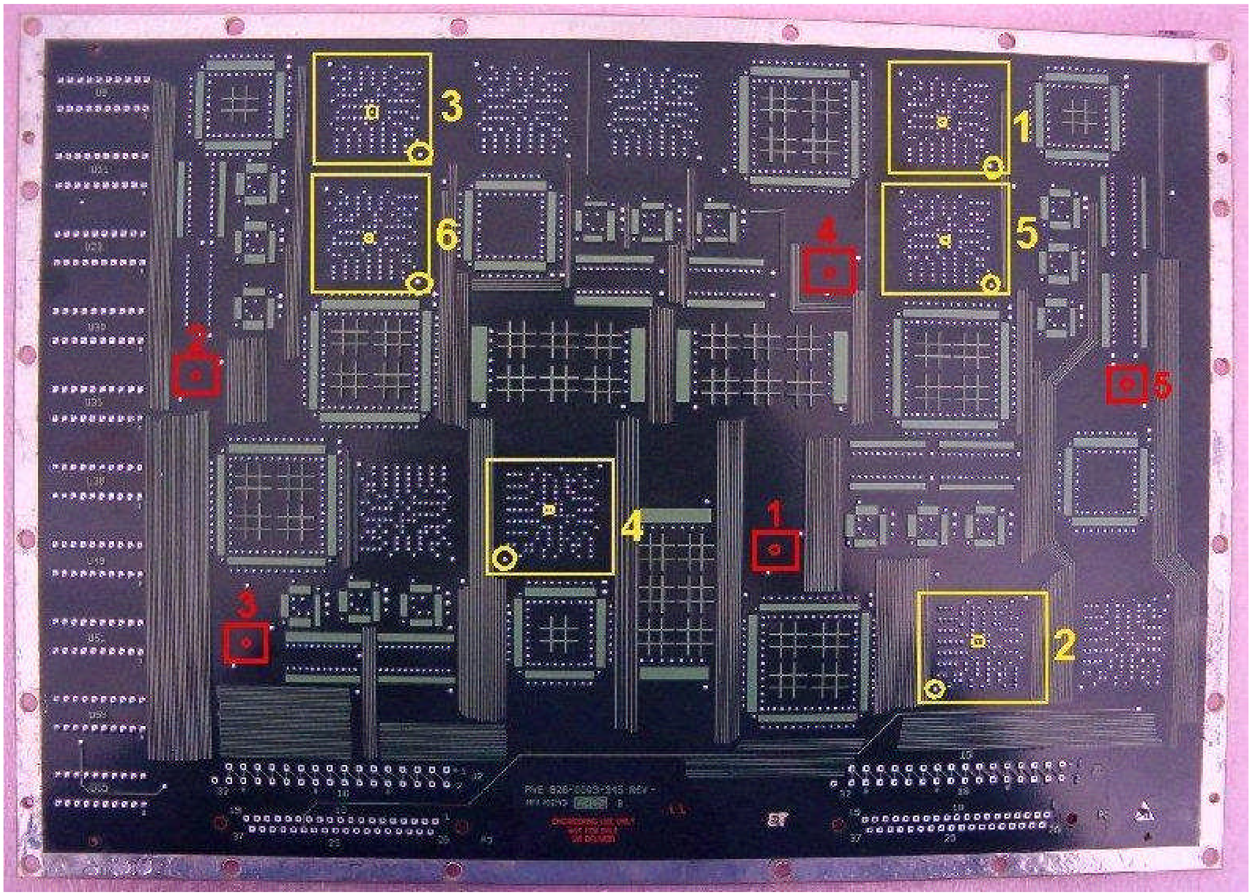


Figure 24 Thermal Couple Map, Bottom Side of the Test Vehicle**

** A JCAA/JGPP test vehicle was used for the thermal couple map since this work was done prior to the NASA-DoD test vehicles being available

- Tape off all areas around the component being reworked
- Hot air rework station with nitrogen per IPC-7711 3.9.1
  - Use regular or tacky flux, document type of flux
  - Nozzle table
  - Mini stencil
    - All 6 mil thick
    - Stainless steel
    - Laser cut
    - BGA = Standard mini stencil with 10% reduction
    - CSP = Standard mini stencil with 10% reduction

- **SnPb rework profile for area array removal and replacement**
  - o Device joint target = 210°C +/- 5°C
  - o Device top max target = 250°C
  - o Board max = as measured by the board trigger thermal couple; will be recorded
  - o Reflow:
  - o ~60 - 120 seconds @ 140-180 °C
  - o ~60 - 120 seconds above 183 °C
  - o Delta T from center to corner ball = 10°C
  - o Ramp rate = <4°C/sec

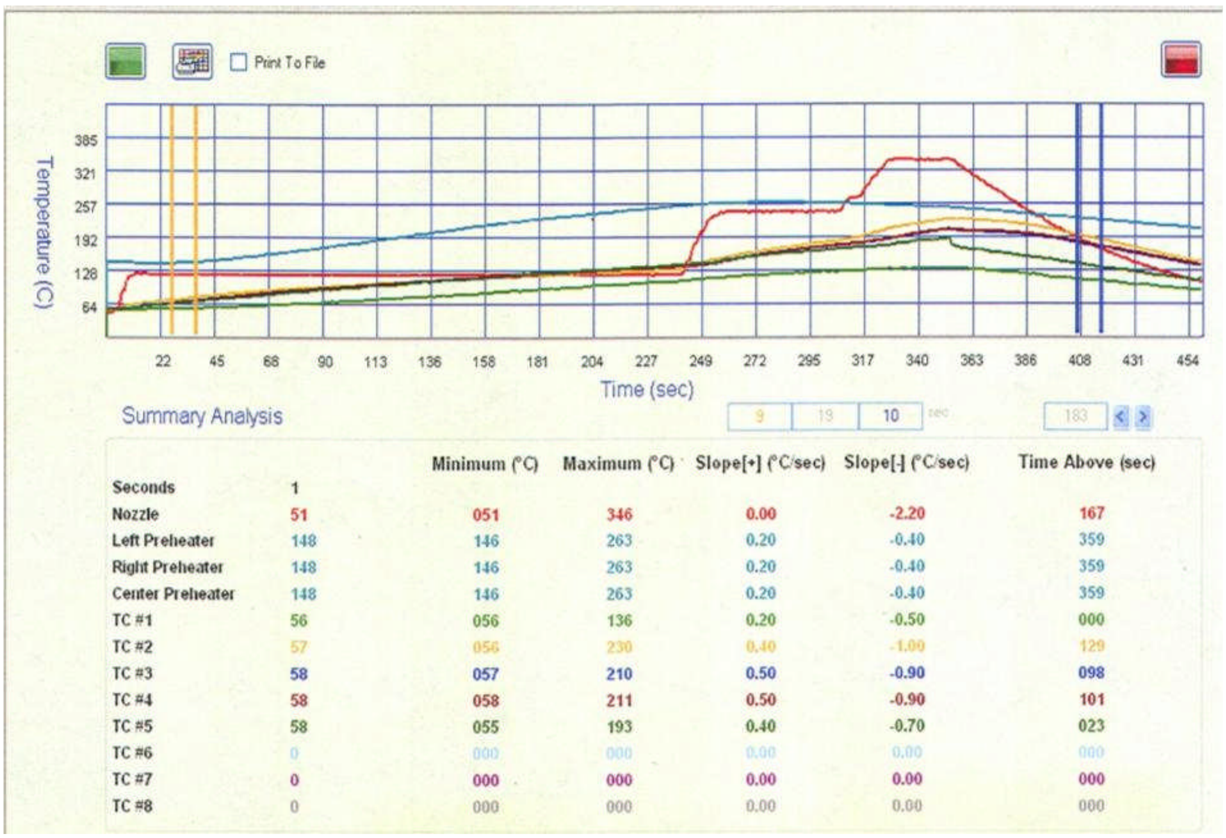
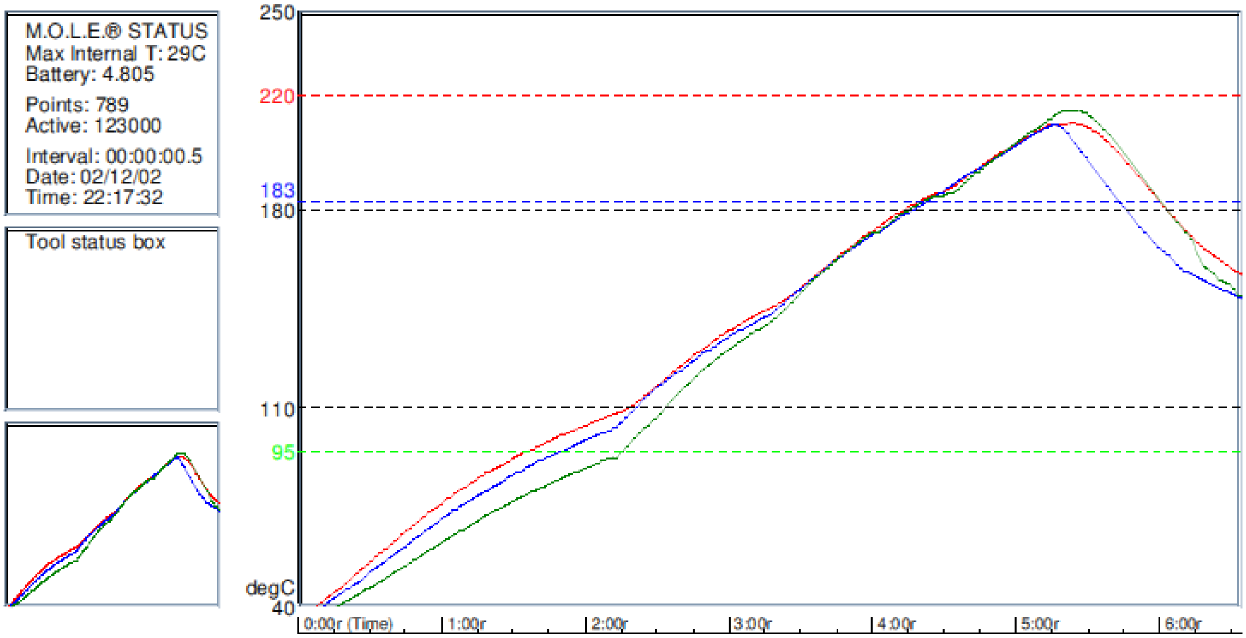


Figure 25 SnPb Rework Profile for BGA components, removal and replacement – BAE Systems

Table 36 Machine Settings for Rework Profiles – SnPb BGA – BAE Systems

	Nozzle	Preheater	Trigger point
Preheat	125	300	110 board
Presoak	225	200	139
Soak	245	200	180
Ramp	275	200	182
Reflow	345	200	209
Max board temp	136		
Max body	230		
Max ball	211		
Dwell	98 sec		



P/N: 828-1507-004

Value	Probe					
	U2 center drilled hole	87	123	170	210	degC
	U2 polarized corner ball	81	122	169	209	degC
	U2 top surface of component	72	114	169	212	degC

P/N: 828-1507-004

T Above Ref	Probe					
	U2 center drilled hole	00:04:58	00:01:41	00:00:00	0%	degC
	U2 polarized corner ball	00:04:44	00:01:21	00:00:00	0%	degC
	U2 top surface of component	00:04:19	00:01:40	00:00:00	0%	degC

P/N: 828-1507-004

Zone Slopes	Probe							
	U2 center drilled hole	NA	NA	NA	NA	NA	NA	degC
	U2 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
	U2 top surface of component	NA	NA	NA	NA	NA	NA	degC

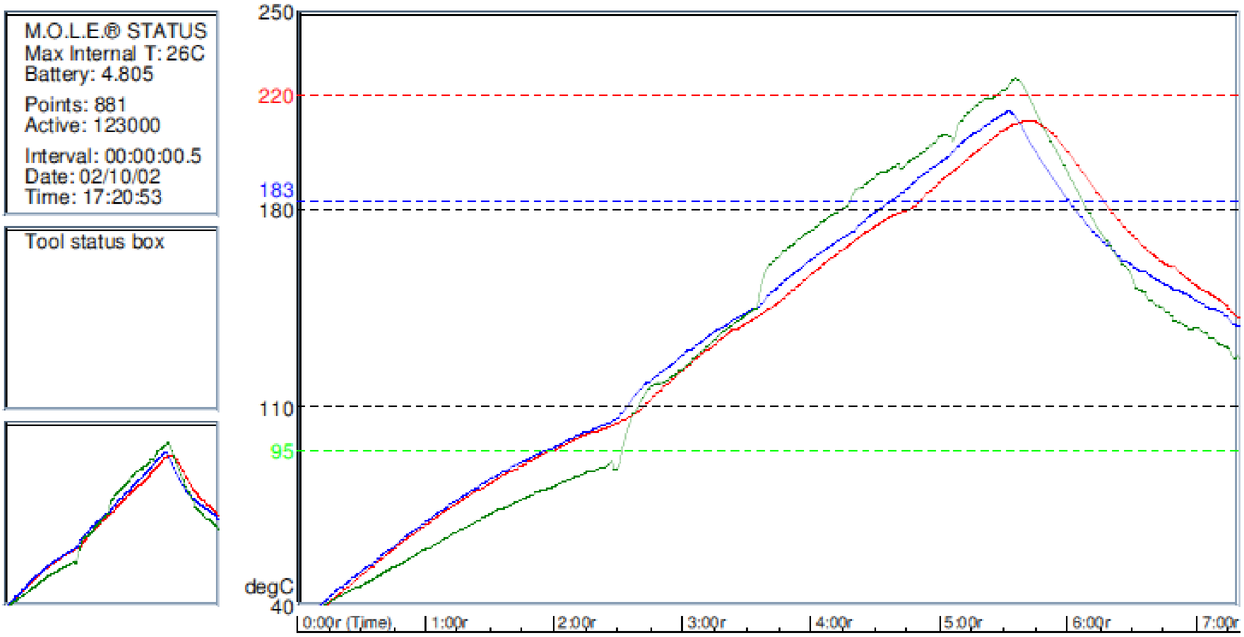
P/N: 828-1507-004

Min-Max	Probe					
	U2 center drilled hole	36	00:00:00r	211	00:05:21r	degC
	U2 polarized corner ball	35	00:00:00r	210	00:05:14r	degC
	U2 top surface of component	35	00:00:00r	215	00:05:20r	degC

P/N: 828-1507-004

Time To Ref	Probe			
	U2 center drilled hole	00:01:35	00:04:18	degC
	U2 polarized corner ball	00:01:50	00:04:22	degC
	U2 top surface of component	00:02:15	00:04:20	degC

Figure 26 SnPb Rework Profile for BGA component (U2), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U6 center drilled hole	82	121	171	207	degC
	U6 polarized corner ball	84	126	176	192	degC
	U6 top surface of component	72	121	188	204	degC

P/N: 828-1507-004

T Above Ref						
	U6 center drilled hole	00:05:21	00:01:26	00:00:00	0%	degC
	U6 polarized corner ball	00:05:24	00:01:24	00:00:00	0%	degC
	U6 top surface of component	00:04:48	00:01:49	00:00:15	0%	degC

P/N: 828-1507-004

Zone Slopes								
	U6 center drilled hole	NA	NA	NA	NA	NA	NA	degC
	U6 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
	U6 top surface of component	NA	NA	NA	NA	NA	NA	degC

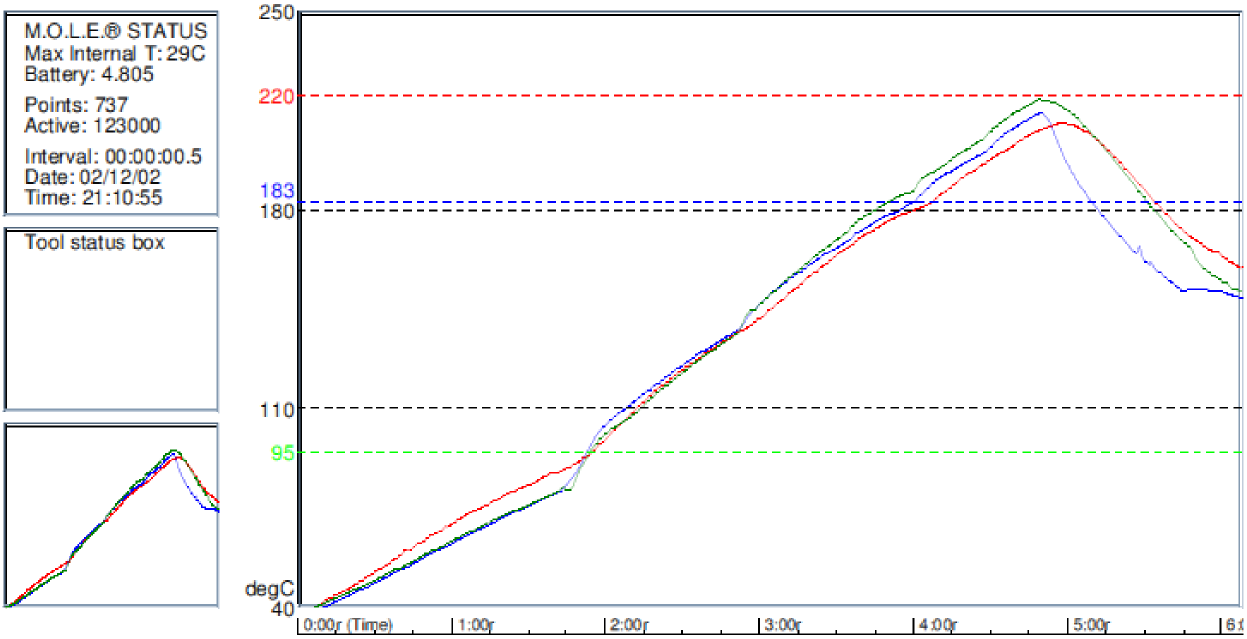
P/N: 828-1507-004

Min-Max						
	U6 center drilled hole	34	00:00:00r	211	00:05:38r	degC
	U6 polarized corner ball	34	00:00:00r	214	00:05:31r	degC
	U6 top surface of component	34	00:00:00r	226	00:05:35r	degC

P/N: 828-1507-004

Time To Ref					
	U6 center drilled hole	00:01:59	00:04:50		degC
	U6 polarized corner ball	00:01:56	00:04:36		degC
	U6 top surface of component	00:02:31	00:04:18	00:05:26	degC

Figure 27 SnPb Rework Profile for BGA component (U6), removal and replacement – Lockheed Martin



P/N: 828-1507-004						
Value	U18 center drilled hole	76	122	171	210	degC
	U18 polarized corner ball	69	124	173	208	degC
	U18 top surface of componei	70	121	178	218	degC

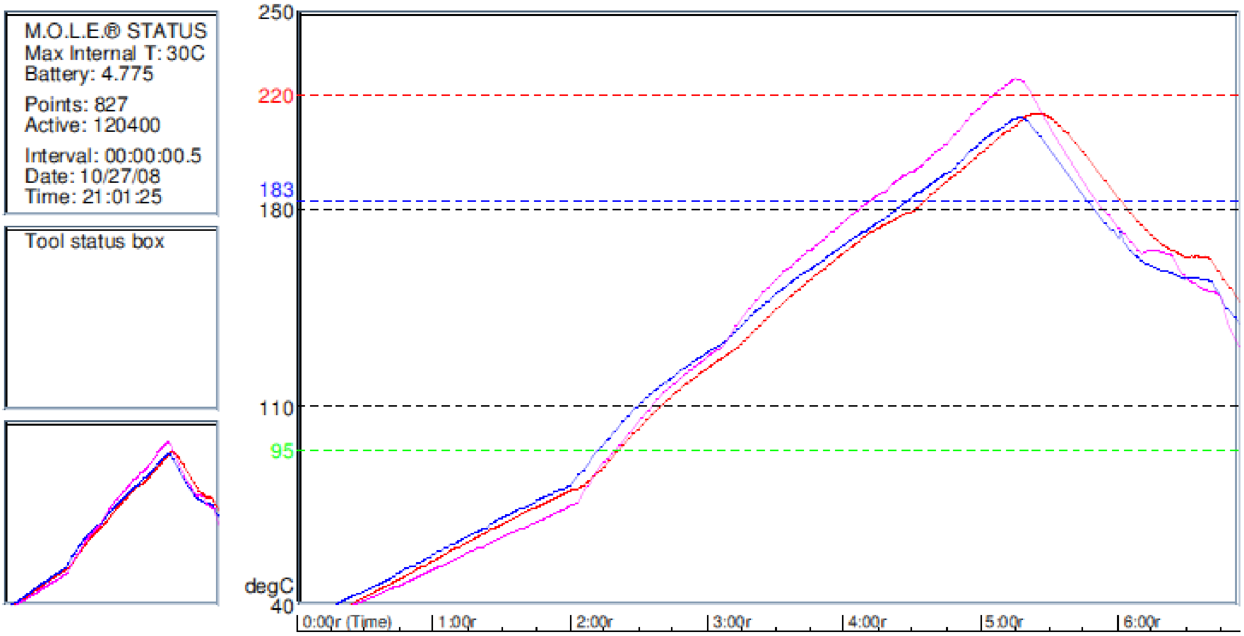
P/N: 828-1507-004						
T Above Ref	U18 center drilled hole	00:04:13	00:01:27	00:00:00	0%	degC
	U18 polarized corner ball	00:04:15	00:01:10	00:00:00	0%	degC
	U18 top surface of componei	00:04:14	00:01:41	00:00:00	0%	degC

P/N: 828-1507-004								
Zone Slopes	U18 center drilled hole	NA	NA	NA	NA	NA	NA	degC
	U18 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
	U18 top surface of componei	NA	NA	NA	NA	NA	NA	degC

P/N: 828-1507-004						
Min-Max	U18 center drilled hole	38	00:00:00r	211	00:04:56r	degC
	U18 polarized corner ball	37	00:00:00r	214	00:04:48r	degC
	U18 top surface of componei	38	00:00:00r	219	00:04:48r	degC

P/N: 828-1507-004				
Time To Ref	U18 center drilled hole	00:01:54	00:04:07	degC
	U18 polarized corner ball	00:01:52	00:03:59	degC
	U18 top surface of componei	00:01:54	00:03:49	degC

Figure 28 SnPb Rework Profile for BGA component (U18), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value					
U21 center drilled hole	66	114	169	212	degC
U21 polarized corner ball	67	121	172	201	degC
U21 top surface of componei	61	118	181	208	degC

P/N: 828-1507-004

T Above Ref					
U21 center drilled hole	00:04:32	00:01:27	00:00:00	0%	degC
U21 polarized corner ball	00:04:41	00:01:19	00:00:00	0%	degC
U21 top surface of componei	00:04:33	00:01:40	00:00:17	0%	degC

P/N: 828-1507-004

Zone Slopes							
U21 center drilled hole	NA	NA	NA	NA	NA	NA	degC
U21 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
U21 top surface of componei	NA	NA	NA	NA	NA	NA	degC

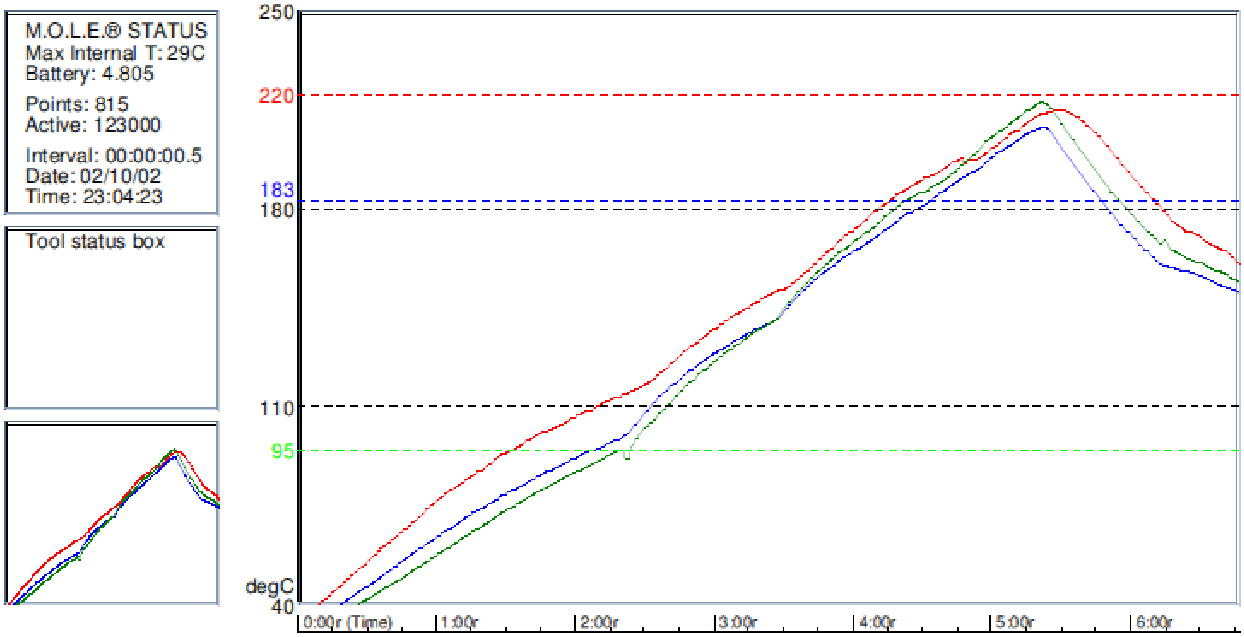
P/N: 828-1507-004

Min-Max					
U21 center drilled hole	34	00:00:00r	213	00:05:21r	degC
U21 polarized corner ball	34	00:00:00r	212	00:05:15r	degC
U21 top surface of componei	34	00:00:00r	226	00:05:14r	degC

P/N: 828-1507-004

Time To Ref				
U21 center drilled hole	00:02:21	00:04:34		degC
U21 polarized corner ball	00:02:11	00:04:27		degC
U21 top surface of componei	00:02:19	00:04:10	00:05:05	degC

Figure 29 SnPb Rework Profile for BGA component (U21), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value					
U43 center drilled hole	89	126	174	214	degC
U43 polarized corner ball	75	118	167	208	degC
U43 top surface of componei	69	113	170	217	degC

P/N: 828-1507-004

T Above Ref					
U43 center drilled hole	00:05:14	00:01:55	00:00:00	0%	degC
U43 polarized corner ball	00:04:40	00:01:14	00:00:00	0%	degC
U43 top surface of componei	00:04:25	00:01:33	00:00:00	0%	degC

P/N: 828-1507-004

Zone Slopes							
U43 center drilled hole	NA	NA	NA	NA	NA	NA	degC
U43 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
U43 top surface of componei	NA	NA	NA	NA	NA	NA	degC

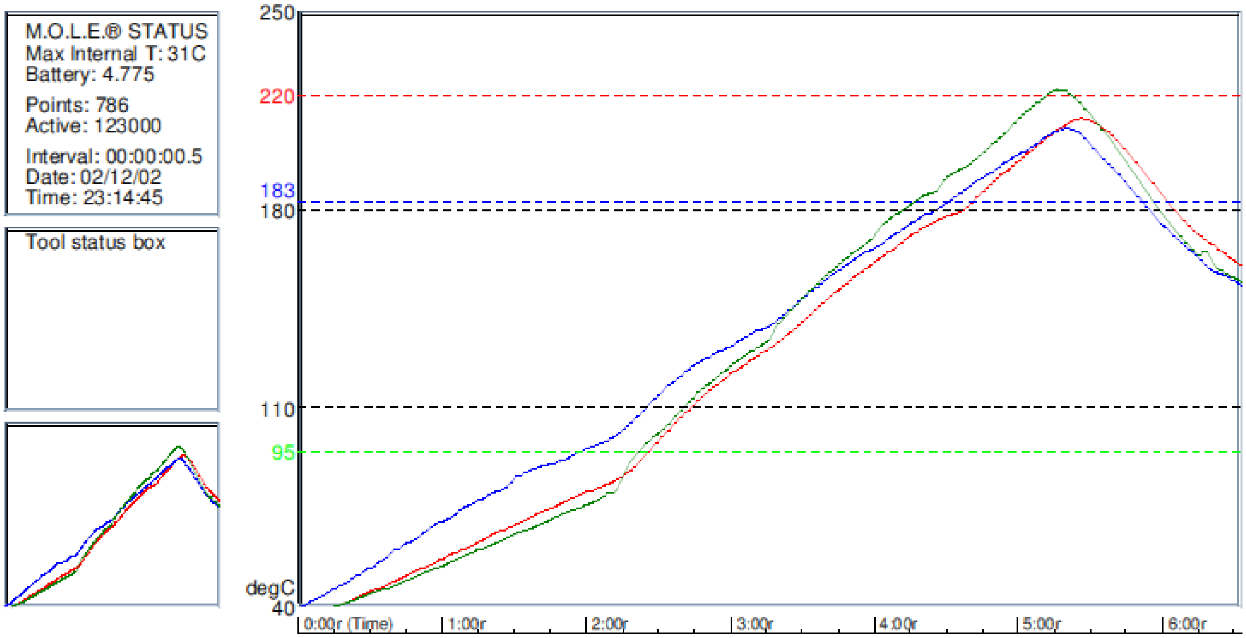
P/N: 828-1507-004

Min-Max					
U43 center drilled hole	35	00:00:00r	214	00:05:26r	degC
U43 polarized corner ball	31	00:00:00r	209	00:05:20r	degC
U43 top surface of componei	31	00:00:00r	218	00:05:20r	degC

P/N: 828-1507-004

Time To Ref			
U43 center drilled hole	00:01:32	00:04:15	degC
U43 polarized corner ball	00:02:07	00:04:33	degC
U43 top surface of componei	00:02:19	00:04:22	degC

Figure 30 SnPb Rework Profile for BGA component (U43), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U56 center drilled hole	64	105	159	207	degC
	U56 polarized corner ball	79	120	165	207	degC
	U56 top surface of componei	61	107	168	222	degC

P/N: 828-1507-004

T Above Ref						
	U56 center drilled hole	00:04:06	00:01:21	00:00:00	0%	degC
	U56 polarized corner ball	00:04:35	00:01:21	00:00:00	0%	degC
	U56 top surface of componei	00:04:11	00:01:40	00:00:11	0%	degC

P/N: 828-1507-004

Zone Slopes								
	U56 center drilled hole	NA	NA	NA	NA	NA	NA	degC
	U56 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
	U56 top surface of componei	NA	NA	NA	NA	NA	NA	degC

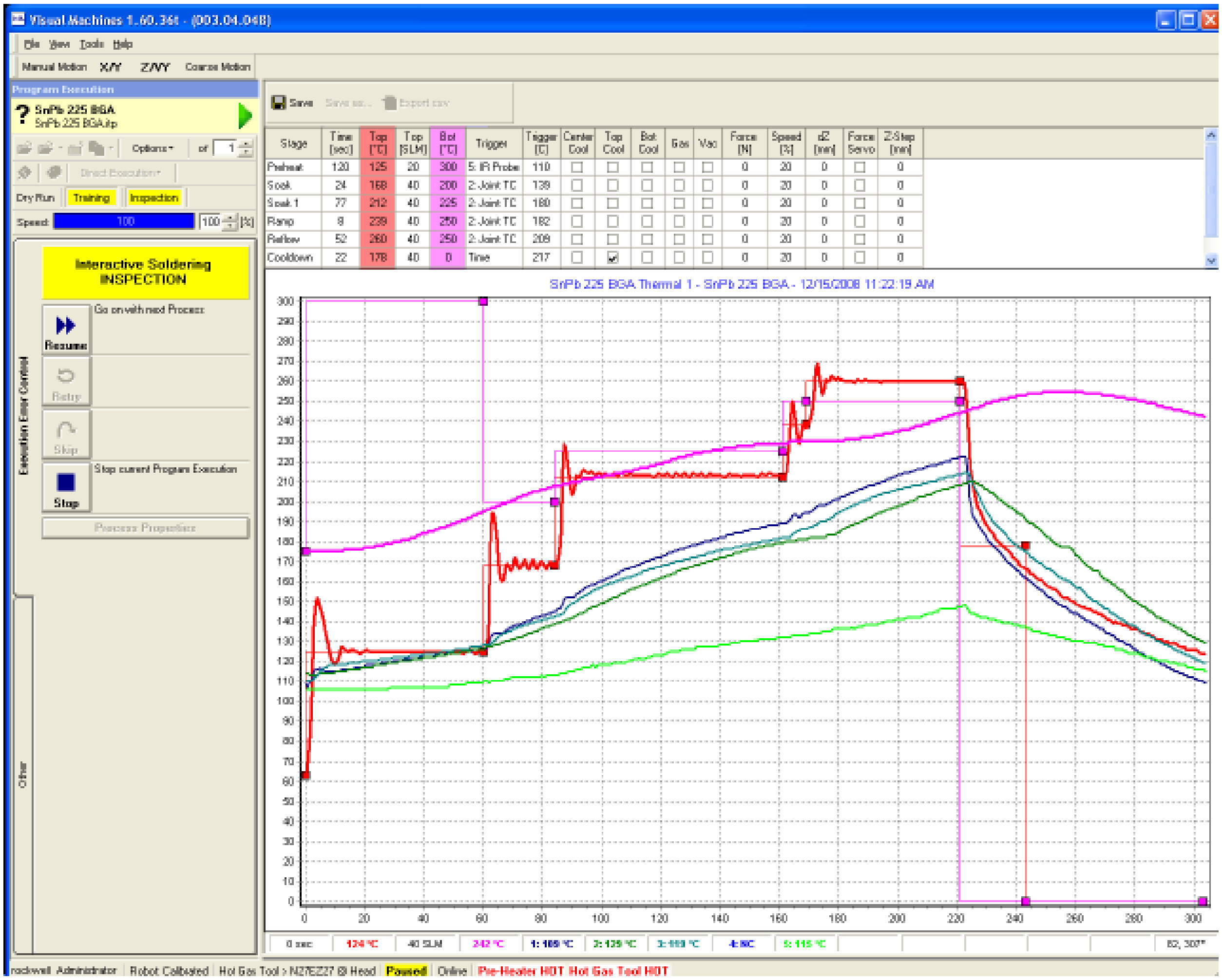
P/N: 828-1507-004

Min-Max						
	U56 center drilled hole	37	00:00:00r	212	00:05:25r	degC
	U56 polarized corner ball	40	00:00:00r	209	00:05:17r	degC
	U56 top surface of componei	37	00:00:00r	223	00:05:15r	degC

P/N: 828-1507-004

Time To Ref					
	U56 center drilled hole	00:02:26	00:04:40		degC
	U56 polarized corner ball	00:01:57	00:04:30		degC
	U56 top surface of componei	00:02:21	00:04:16	00:05:11	degC

Figure 31 SnPb Rework Profile for BGA component (U56), removal and replacement – Lockheed Martin



[Figure](#) 32 SnPb Rework Profile for BGA component, removal and replacement – Rockwell Collins

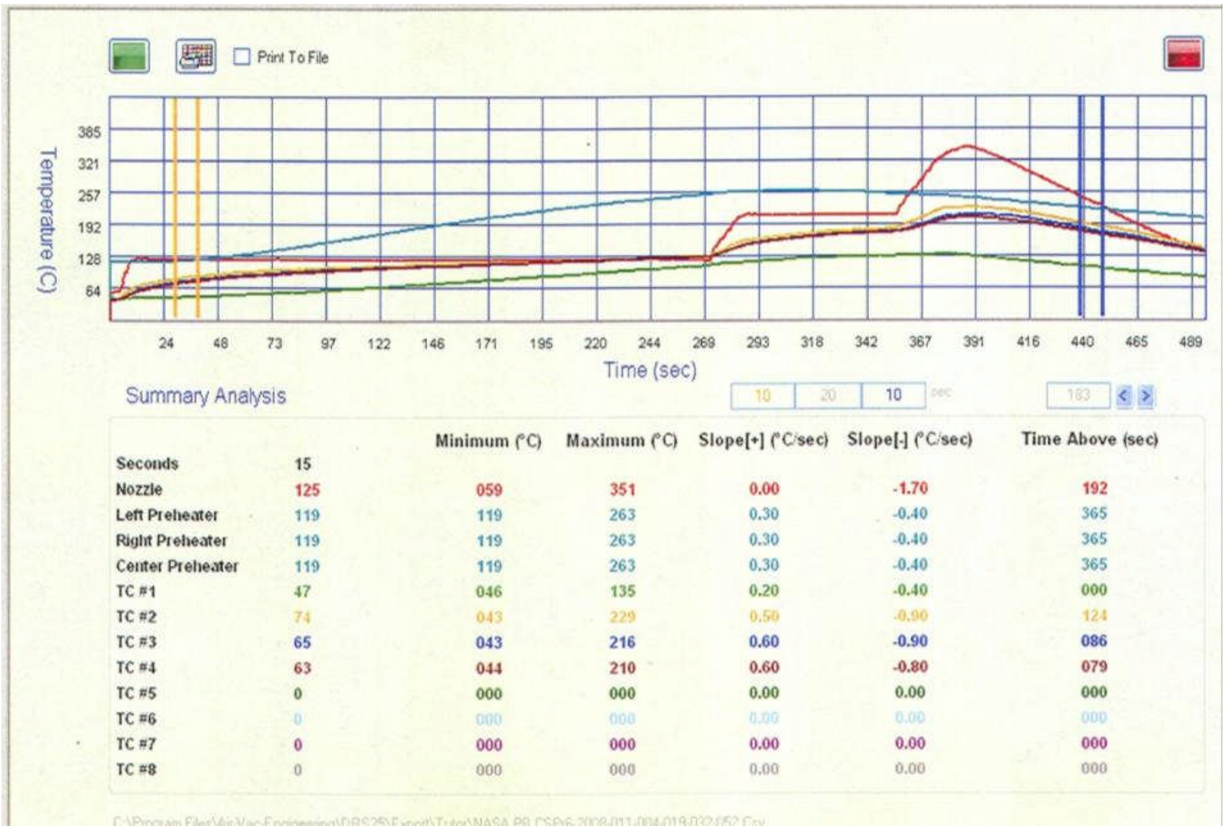


Figure 33 SnPb Rework Profile for CSP components, removal and replacement – BAE Systems

Table 37 Machine Settings for Rework Profiles – SnPb CSP – BAE Systems

	Nozzle	Preheater	Trigger point
Preheat	125	300	110 board
Presoak	215	200	139
Soak	215	200	180
Ramp	275	225	182
Reflow	335	225	209
Max board temp	135		
Max body	229		
Max ball	216		
Dwell	86 sec		

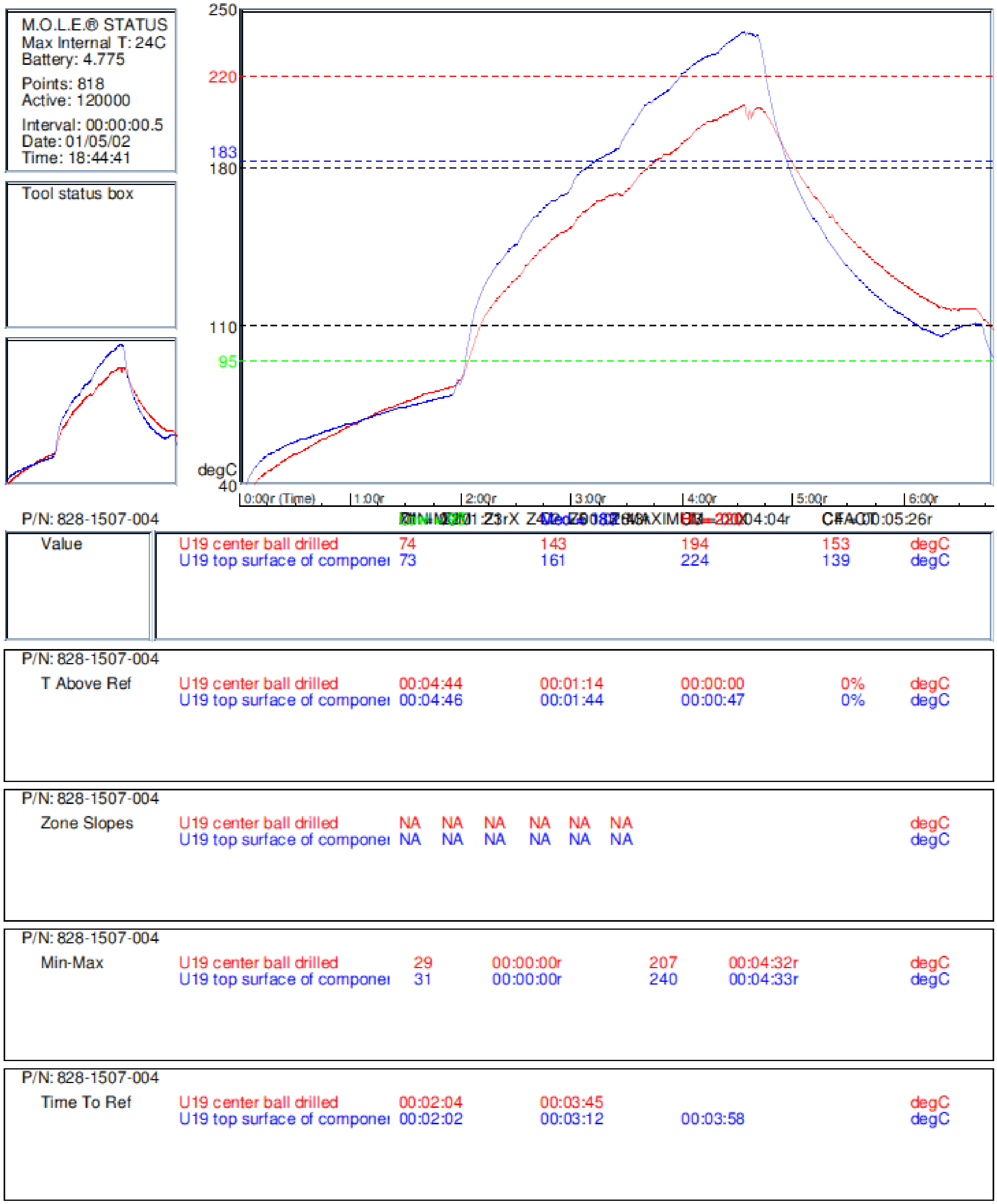
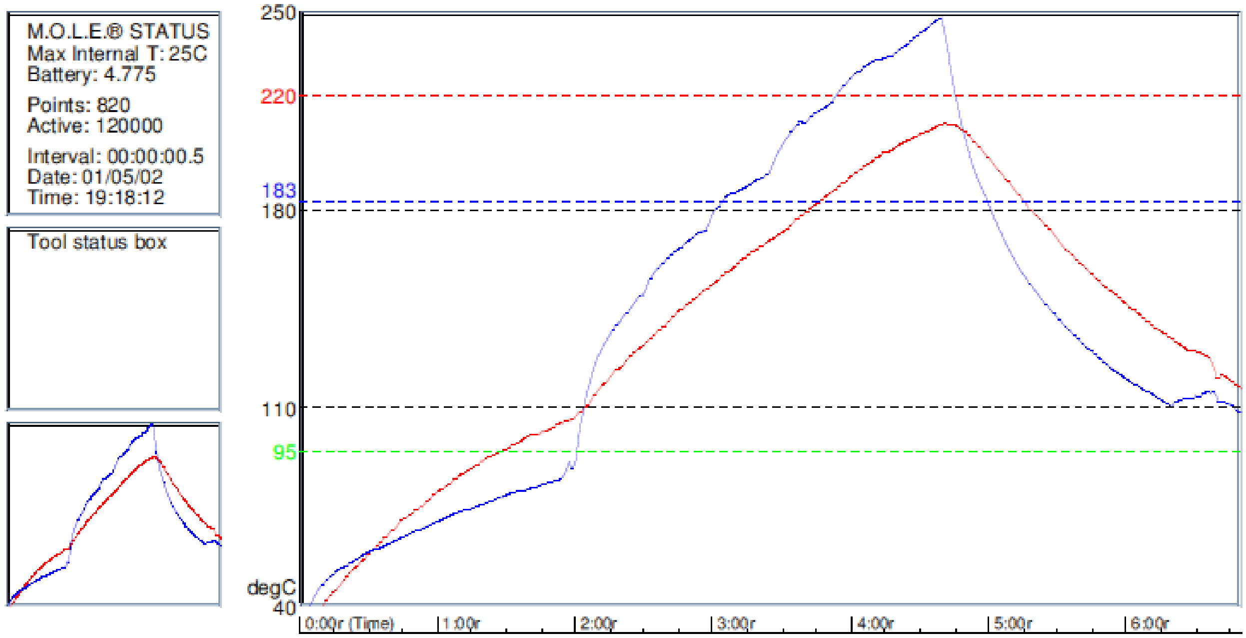


Figure 34 SnPb Rework Profile for CSP component (U19), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U33 center ball drilled	93	143	194	173	degC
	U33 top surface of componei	77	165	229	145	degC

P/N: 828-1507-004

T Above Ref						
	U33 center ball drilled	00:05:22	00:01:29	00:00:00	0%	degC
	U33 top surface of componei	00:04:49	00:01:56	00:00:52	0%	degC

P/N: 828-1507-004

Zone Slopes								
	U33 center ball drilled	NA	NA	NA	NA	NA	NA	degC
	U33 top surface of componei	NA	NA	NA	NA	NA	NA	degC

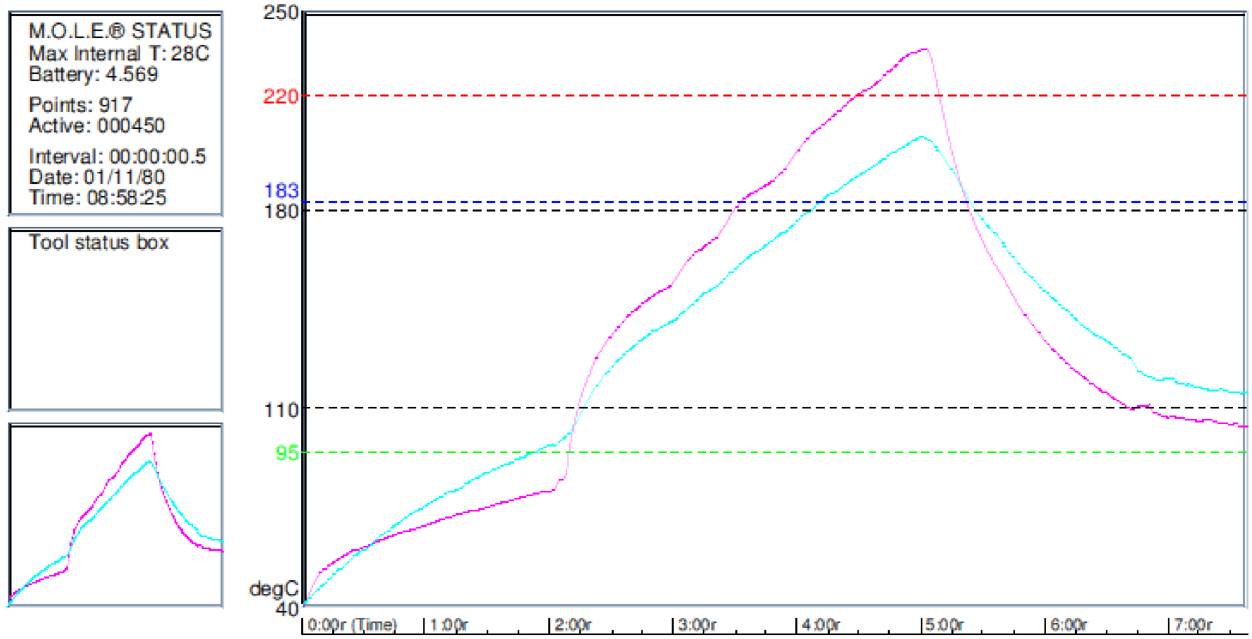
P/N: 828-1507-004

Min-Max						
	U33 center ball drilled	33	00:00:00r	211	00:04:40r	degC
	U33 top surface of componei	29	00:00:00r	248	00:04:39r	degC

P/N: 828-1507-004

Time To Ref					
	U33 center ball drilled	00:01:27	00:03:46		degC
	U33 top surface of componei	00:02:00	00:03:03	00:03:53	degC

Figure 35 SnPb Rework Profile for CSP component (U33), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value					
U37 top surface of compone	76	158	223	129	degC
U37 center ball drilled	88	143	194	147	degC

P/N: 828-1507-004

T Above Ref

U37 top surface of compone	00:05:28	00:01:50	00:00:41	0%	degC
U37 center ball drilled	00:05:46	00:01:13	00:00:00	0%	degC

P/N: 828-1507-004

Zone Slopes

U37 top surface of compone	NA	NA	NA	NA	NA	NA	degC
U37 center ball drilled	NA	NA	NA	NA	NA	NA	degC

P/N: 828-1507-004

Min-Max

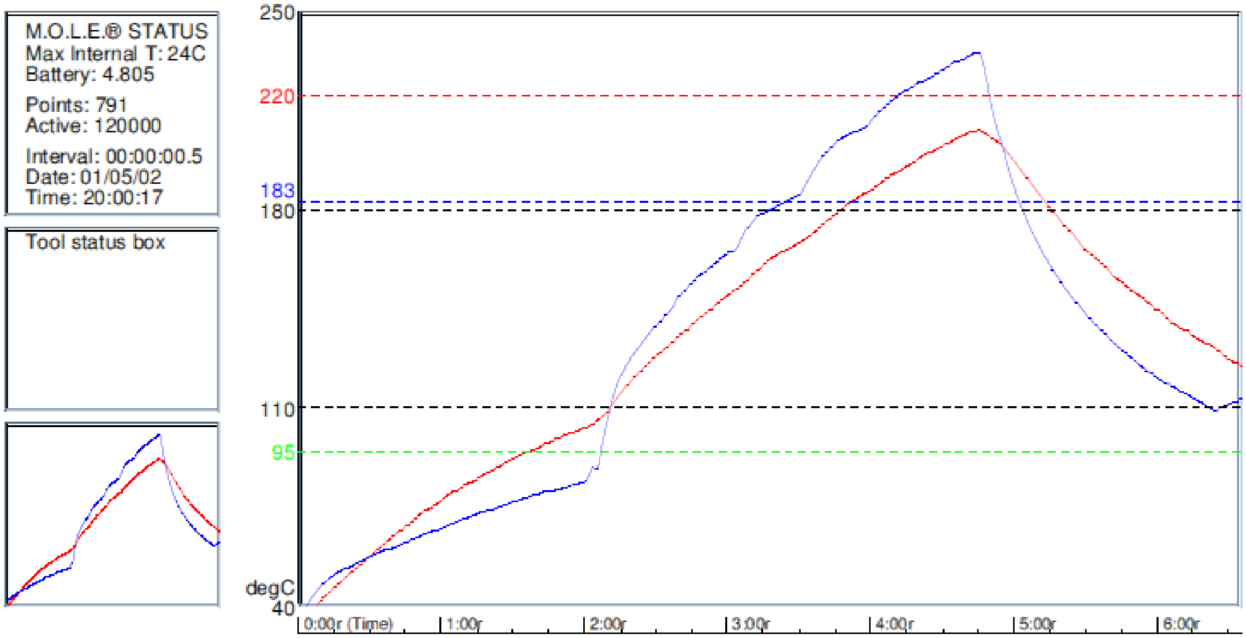
U37 top surface of compone	40	00:00:00r	237	00:04:59r	degC
U37 center ball drilled	42	00:00:00r	206	00:04:59r	degC

P/N: 828-1507-004

Time To Ref

U37 top surface of compone	00:02:09	00:03:32	00:04:28	degC
U37 center ball drilled	00:01:52	00:04:10		degC

Figure 36 SnPb Rework Profile for CSP component (U37), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U42 center ball drilled	87	134	186	179	degC
	U42 top surface of compone	74	148	209	159	degC

P/N: 828-1507-004

T Above Ref						
	U42 center ball drilled	00:04:58	00:01:22	00:00:00	0%	degC
	U42 top surface of compone	00:04:28	00:01:38	00:00:38	0%	degC

P/N: 828-1507-004

Zone Slopes								
	U42 center ball drilled	NA	NA	NA	NA	NA	NA	degC
	U42 top surface of compone	NA	NA	NA	NA	NA	NA	degC

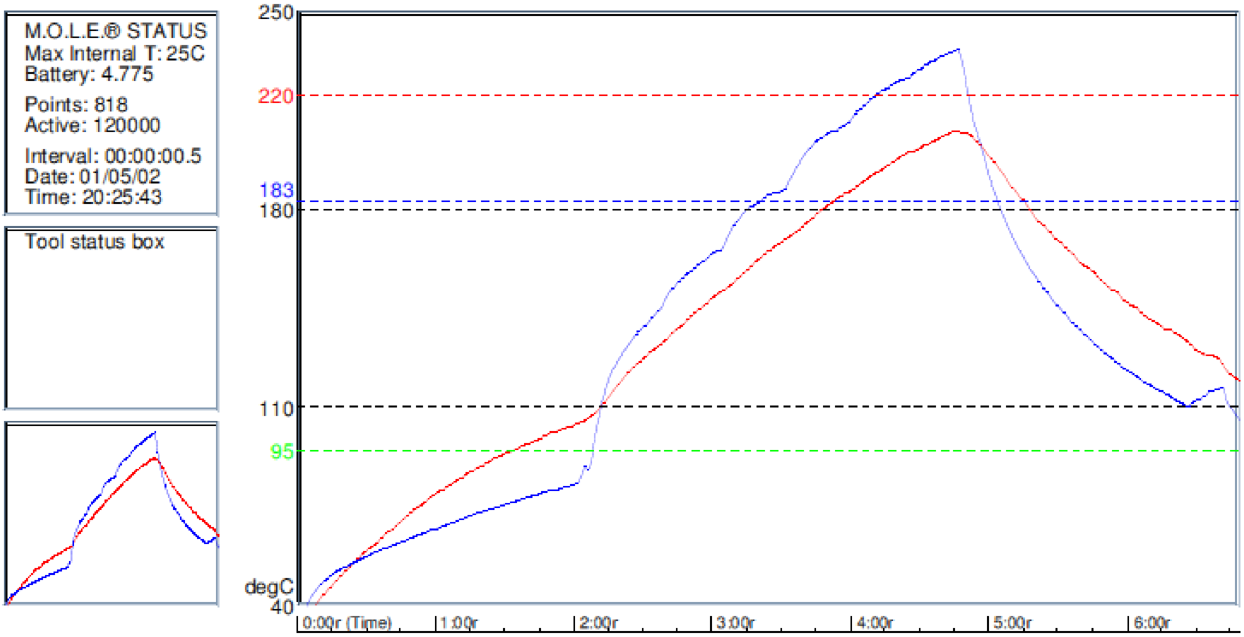
P/N: 828-1507-004

Min-Max						
	U42 center ball drilled	33	00:00:00r	208	00:04:44r	degC
	U42 top surface of compone	33	00:00:00r	236	00:04:44r	degC

P/N: 828-1507-004

Time To Ref					
	U42 center ball drilled	00:01:36	00:03:51		degC
	U42 top surface of compone	00:02:07	00:03:23	00:04:11	degC

Figure 37 SnPb Rework Profile for CSP component (U42), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U50 center ball drilled	91	137	189	172	degC
	U50 top surface of componei	73	152	216	149	degC

P/N: 828-1507-004

T Above Ref						
	U50 center ball drilled	00:05:15	00:01:23	00:00:00	0%	degC
	U50 top surface of componei	00:04:40	00:01:43	00:00:40	0%	degC

P/N: 828-1507-004

Zone Slopes								
	U50 center ball drilled	NA	NA	NA	NA	NA	NA	degC
	U50 top surface of componei	NA	NA	NA	NA	NA	NA	degC

P/N: 828-1507-004

Min-Max						
	U50 center ball drilled	34	00:00:00r	208	00:04:45r	degC
	U50 top surface of componei	31	00:00:00r	237	00:04:46r	degC

P/N: 828-1507-004

Time To Ref					
	U50 center ball drilled	00:01:33	00:03:52		degC
	U50 top surface of componei	00:02:08	00:03:20	00:04:10	degC

Figure 38 SnPb Rework Profile for CSP component (U50), removal and replacement – Lockheed Martin

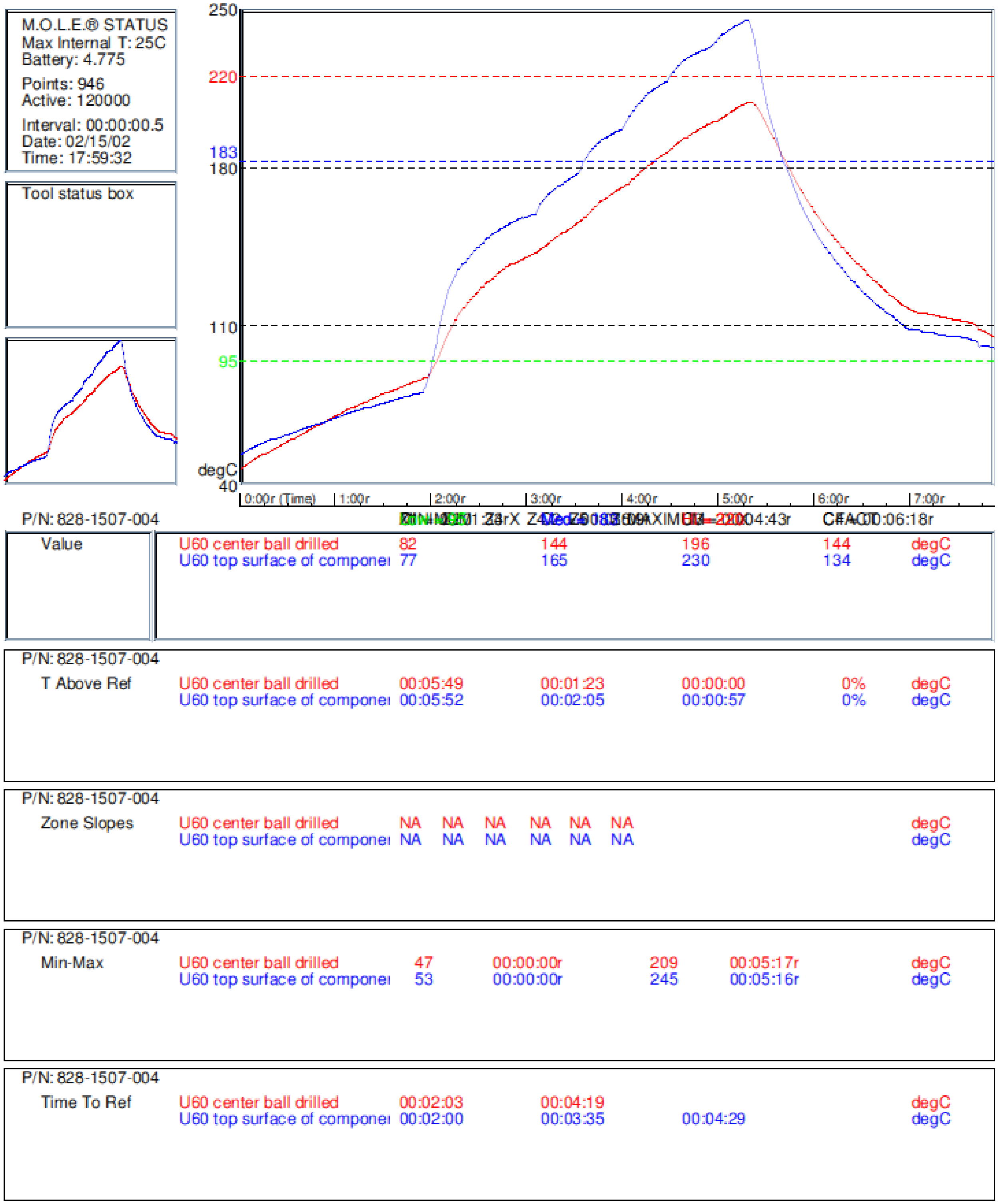
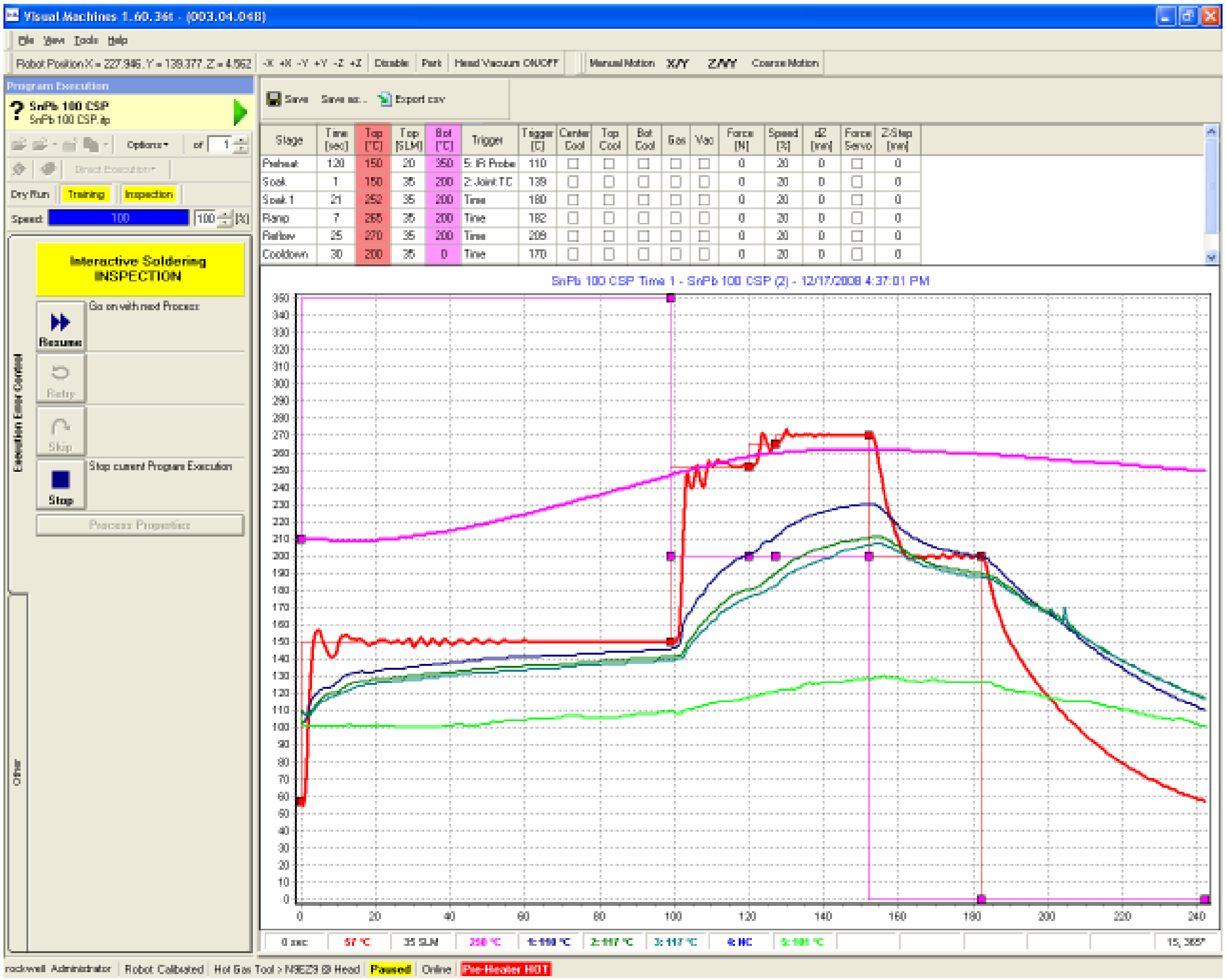


Figure 39 SnPb Rework Profile for CSP component (U60), removal and replacement – Lockheed Martin



[Figure](#) **40 SnPb Rework Profile for CSP component, removal and replacement – Rockwell Collins**

- **Lead-Free rework profile for area array removal and replacement**
    - Device joint target = 240°C +/- 5°C
    - Device top max target = 260°C
    - Board max = as measured by the board trigger thermal couple; will be recorded
    - Reflow:
    - ~60 - 120 seconds @ 170-205°C
    - ~60 - 120 seconds above liquidus of alloy
    - Delta T from center to corner ball = 10°C
    - Ramp rate = <4°C/sec

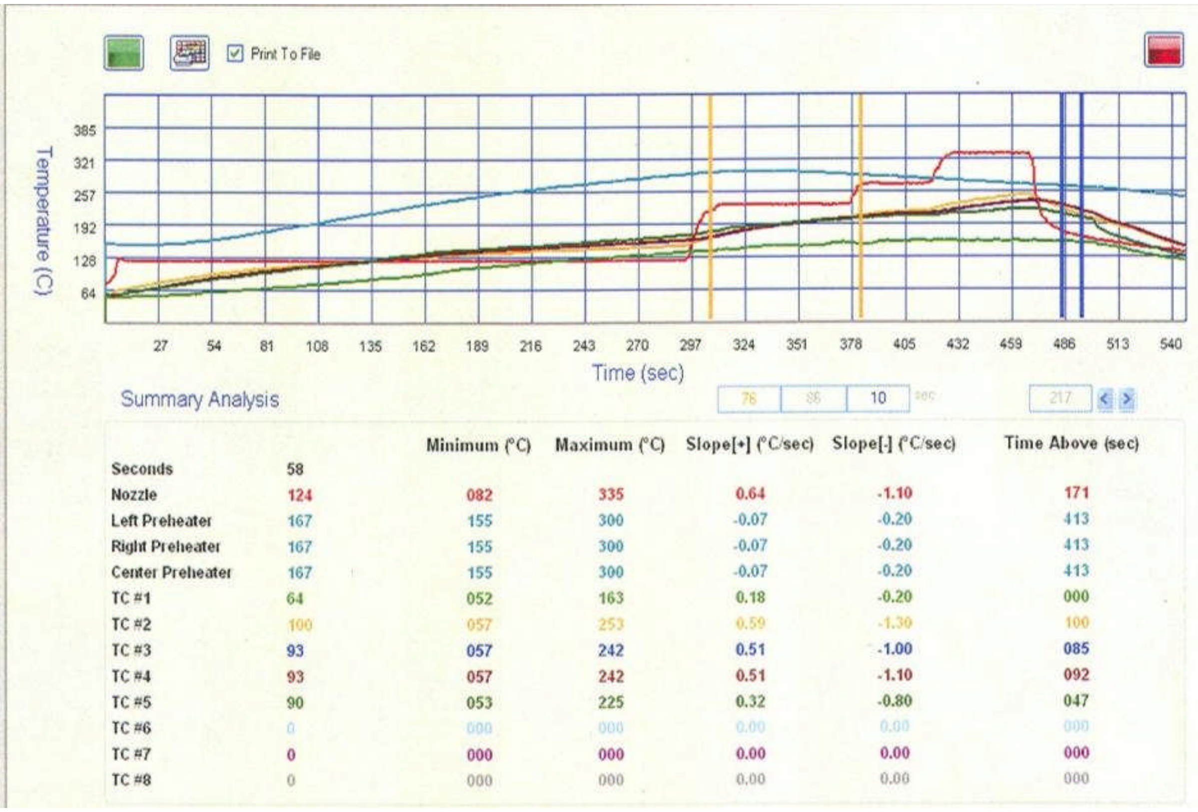
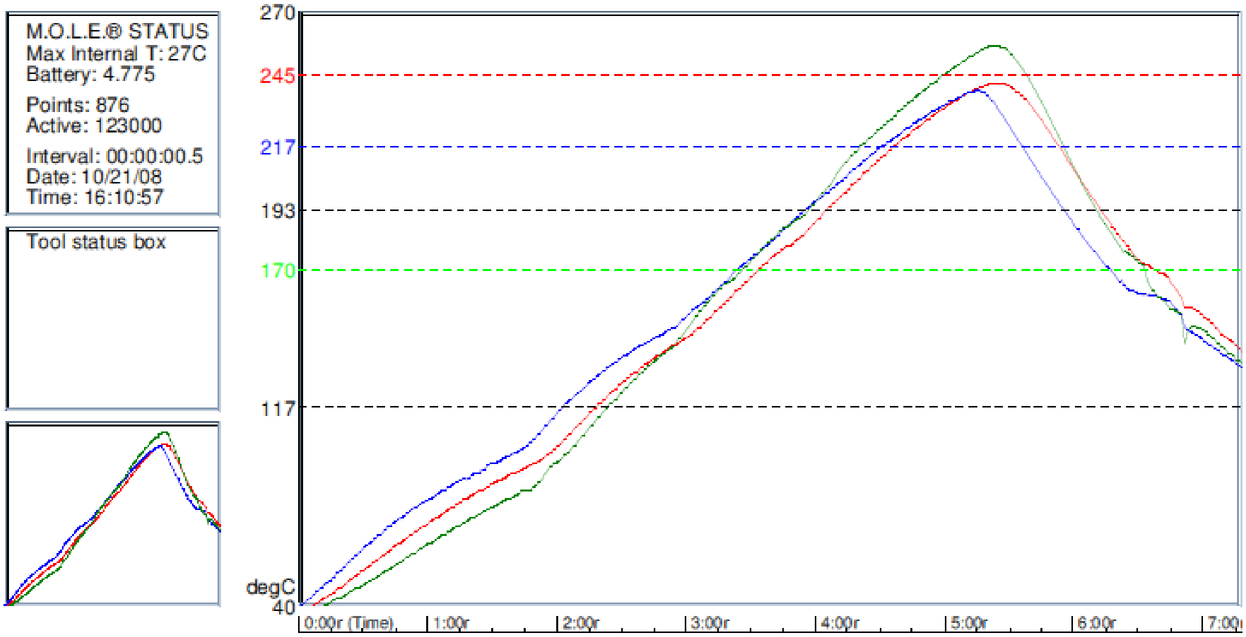


Figure 41 Lead-Free Rework Profile for BGA components, removal and replacement – BAE Systems

Table 38 Machine Settings for Rework Profiles – Lead-Free BGA – BAE Systems

	Nozzle	Preheater	Trigger point
Preheat	125	325	140 board
Presoak	225	200	169
Soak	235	200	205
Ramp	275	225	216
Reflow	335	250	40
Max board temp	163		
Max body	253		
Max ball	242		
Dwell	85 sec		



P/N: 828-1507-004

Value					
U2 center ball drilled	86	162	205	221	degC
U2 polarized corner ball	94	170	211	199	degC
U2 top surface component di	77	167	217	226	degC

P/N: 828-1507-004

T Above Ref					
U2 center ball drilled	00:03:05	00:01:18	00:00:00	0%	degC
U2 polarized corner ball	00:02:54	00:01:07	00:00:00	0%	degC
U2 top surface component di	00:03:07	00:01:35	00:00:40	0%	degC

P/N: 828-1507-004

Zone Slopes							
U2 center ball drilled	NA	NA	NA	NA	NA	NA	degC
U2 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
U2 top surface component di	NA	NA	NA	NA	NA	NA	degC

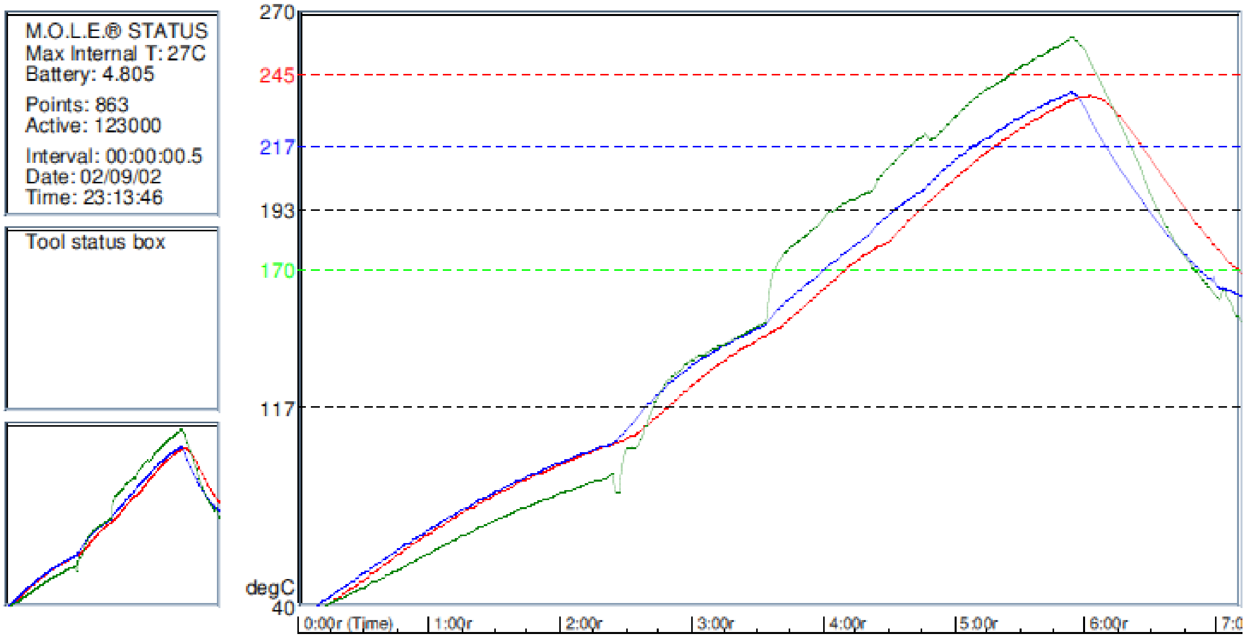
P/N: 828-1507-004

Min-Max					
U2 center ball drilled	38	00:00:00r	242	00:05:23r	degC
U2 polarized corner ball	39	00:00:00r	240	00:05:14r	degC
U2 top surface component di	37	00:00:00r	257	00:05:20r	degC

P/N: 828-1507-004

Time To Ref				
U2 center ball drilled	00:03:33	00:04:35		degC
U2 polarized corner ball	00:03:22	00:04:29		degC
U2 top surface component di	00:03:25	00:04:20	00:04:58	degC

Figure 42 Lead-Free Rework Profile for BGA component (U2), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U6 center ball drilled	82	162	205	232	degC
	U6 polarized corner ball	82	170	212	235	degC
	U6 top surface of component	72	189	229	255	degC

P/N: 828-1507-004

T Above Ref						
	U6 center ball drilled	00:03:00	00:01:08	00:00:00	0%	degC
	U6 polarized corner ball	00:02:52	00:01:02	00:00:00	0%	degC
	U6 top surface of component	00:03:12	00:01:42	00:00:40	0%	degC

P/N: 828-1507-004

Zone Slopes								
U6 center ball drilled	NA	NA	NA	NA	NA	NA	degC
U6 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
U6 top surface of component	NA	NA	NA	NA	NA	NA	degC

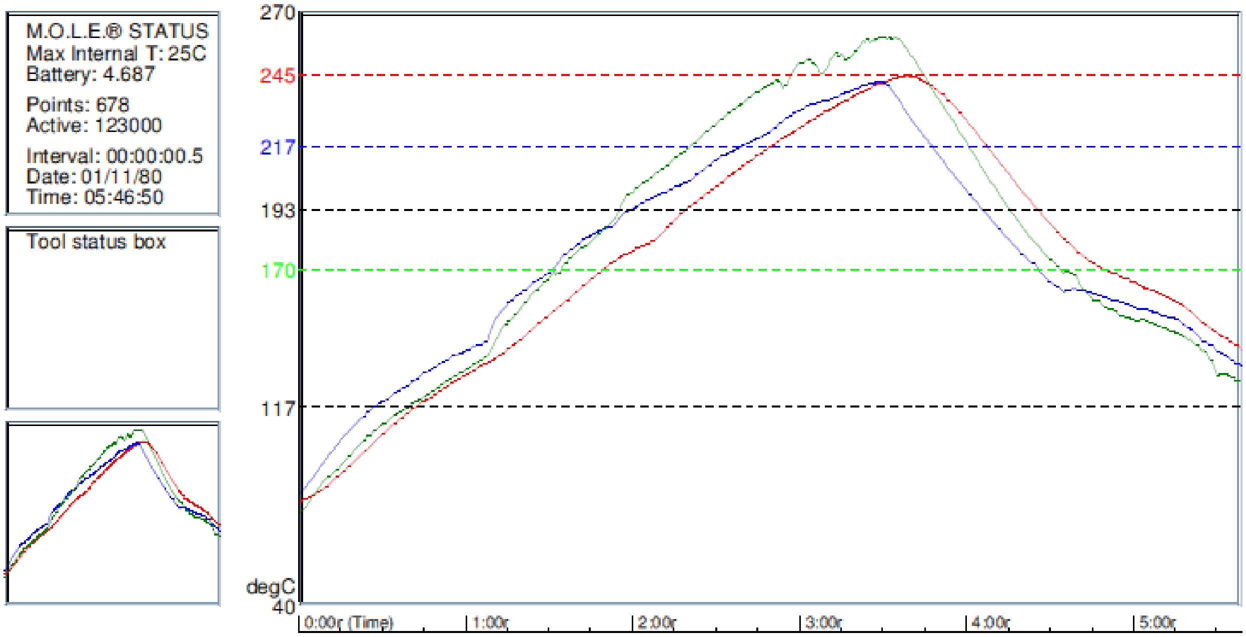
P/N: 828-1507-004

Min-Max						
	U6 center ball drilled	35	00:00:00r	237	00:06:01r	degC
	U6 polarized corner ball	36	00:00:00r	238	00:05:52r	degC
	U6 top surface of component	34	00:00:00r	260	00:05:52r	degC

P/N: 828-1507-004

Time To Ref					
	U6 center ball drilled	00:04:09	00:05:17		degC
	U6 polarized corner ball	00:03:59	00:05:07		degC
	U6 top surface of component	00:03:37	00:04:38	00:05:25	degC

Figure 43 Lead-Free Rework Profile for BGA component (U6), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U18 center ball drilled	134	154	205	187	degC
	U18 polarized corner ball	142	170	214	165	degC
	U18 top surface component	137	168	229	174	degC

P/N: 828-1507-004

T Above Ref						
	U18 center ball drilled	00:03:01	00:01:19	00:00:01	0%	degC
	U18 polarized corner ball	00:02:54	00:01:10	00:00:00	0%	degC
	U18 top surface component	00:02:59	00:01:41	00:00:48	0%	degC

P/N: 828-1507-004

Zone Slopes								
	U18 center ball drilled	NA	NA	NA	NA	NA	NA	degC
	U18 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
	U18 top surface component	NA	NA	NA	NA	NA	NA	degC

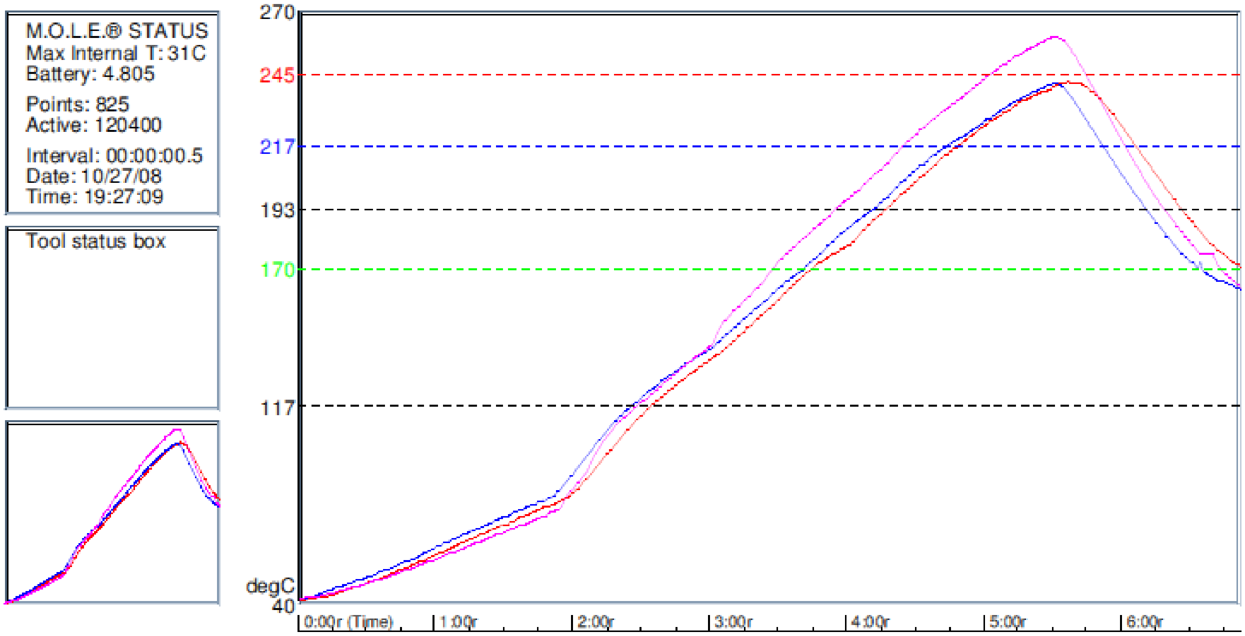
P/N: 828-1507-004

Min-Max						
	U18 center ball drilled	81	00:00:00r	245	00:03:37r	degC
	U18 polarized corner ball	83	00:00:00r	243	00:03:27r	degC
	U18 top surface component	76	00:00:00r	260	00:03:34r	degC

P/N: 828-1507-004

Time To Ref					
	U18 center ball drilled	00:01:49	00:02:48	00:03:37	degC
	U18 polarized corner ball	00:01:31	00:02:38		degC
	U18 top surface component	00:01:34	00:02:20	00:02:56	degC

Figure 44 Lead-Free Rework Profile for BGA component (U18), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value						
	U21 center ball drilled	68	167	205	239	degC
	U21 polarized corner ball	71	170	209	241	degC
	U21 top surface component (	66	182	223	259	degC

P/N: 828-1507-004

T Above Ref						
	U21 center ball drilled	00:03:08	00:01:18	00:00:00	0%	degC
	U21 polarized corner ball	00:02:54	00:01:09	00:00:00	0%	degC
	U21 top surface component (	00:03:16	00:01:38	00:00:43	0%	degC

P/N: 828-1507-004

Zone Slopes								
	U21 center ball drilled	NA	NA	NA	NA	NA	NA	degC
	U21 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
	U21 top surface component (	NA	NA	NA	NA	NA	NA	degC

P/N: 828-1507-004

Min-Max						
	U21 center ball drilled	42	00:00:00r	243	00:05:36r	degC
	U21 polarized corner ball	42	00:00:00r	242	00:05:29r	degC
	U21 top surface component (	42	00:00:00r	259	00:05:29r	degC

P/N: 828-1507-004

Time To Ref					
	U21 center ball drilled	00:03:44	00:04:48		degC
	U21 polarized corner ball	00:03:40	00:04:43		degC
	U21 top surface component (	00:03:27	00:04:23	00:05:01	degC

Figure 45 Lead-Free Rework Profile for BGA component (U21), removal and replacement – Lockheed Martin

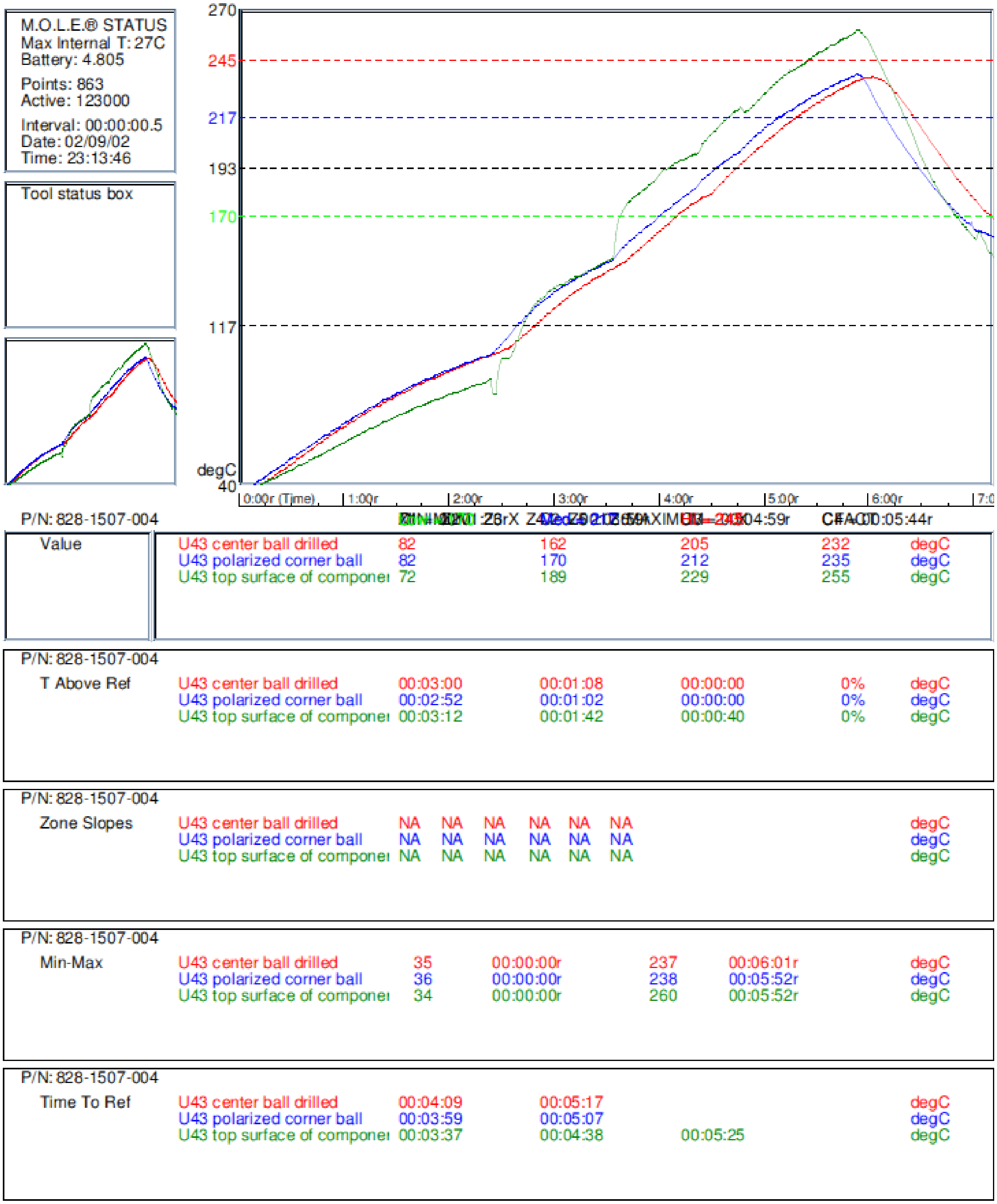
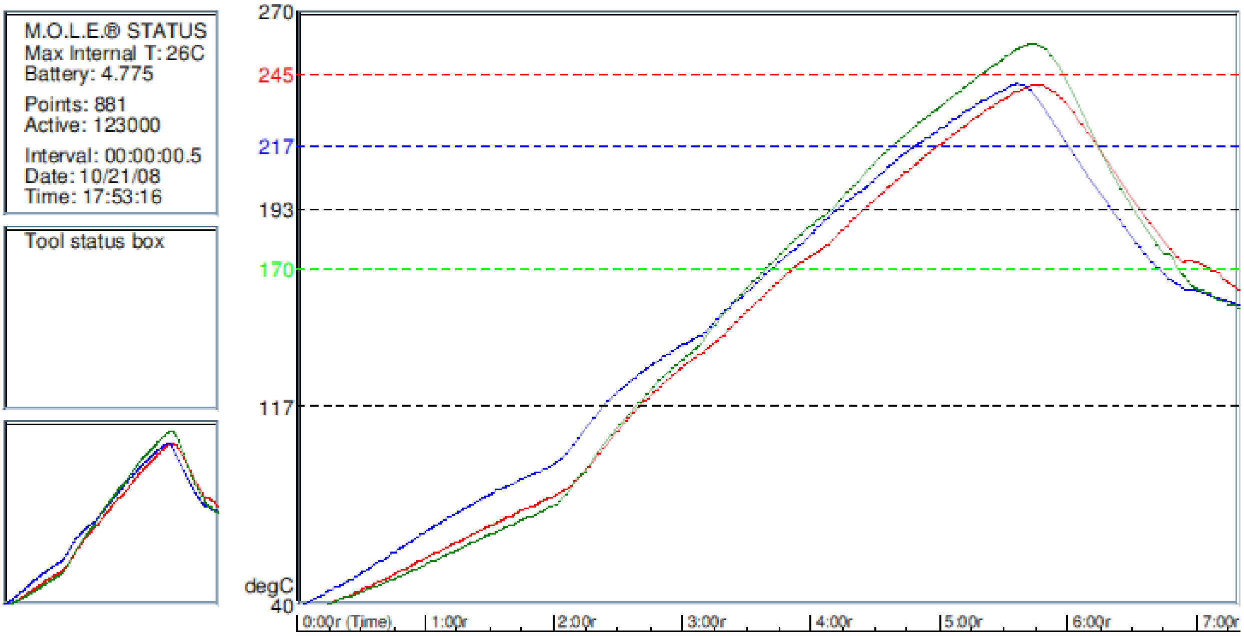


Figure 46 Lead-Free Rework Profile for BGA component (U43), removal and replacement – Lockheed Martin



P/N: 828-1507-004

Value					
U56 center ball drilled	70	163	205	239	degC
U56 polarized corner ball	82	170	213	228	degC
U56 top surface component (	67	172	219	253	degC

P/N: 828-1507-004

T Above Ref					
U56 center ball drilled	00:03:15	00:01:16	00:00:00	0%	degC
U56 polarized corner ball	00:03:02	00:01:13	00:00:00	0%	degC
U56 top surface component (	00:03:13	00:01:37	00:00:39	0%	degC

P/N: 828-1507-004

Zone Slopes							
U56 center ball drilled	NA	NA	NA	NA	NA	NA	degC
U56 polarized corner ball	NA	NA	NA	NA	NA	NA	degC
U56 top surface component (	NA	NA	NA	NA	NA	NA	degC

P/N: 828-1507-004

Min-Max					
U56 center ball drilled	37	00:00:00r	241	00:05:42r	degC
U56 polarized corner ball	40	00:00:00r	242	00:05:35r	degC
U56 top surface component (	37	00:00:00r	257	00:05:41r	degC

P/N: 828-1507-004

Time To Ref				
U56 center ball drilled	00:03:51	00:04:58		degC
U56 polarized corner ball	00:03:41	00:04:47		degC
U56 top surface component (	00:03:38	00:04:37	00:05:18	degC

Figure 47 Lead-Free Rework Profile for BGA component (U56), removal and replacement – Lockheed Martin

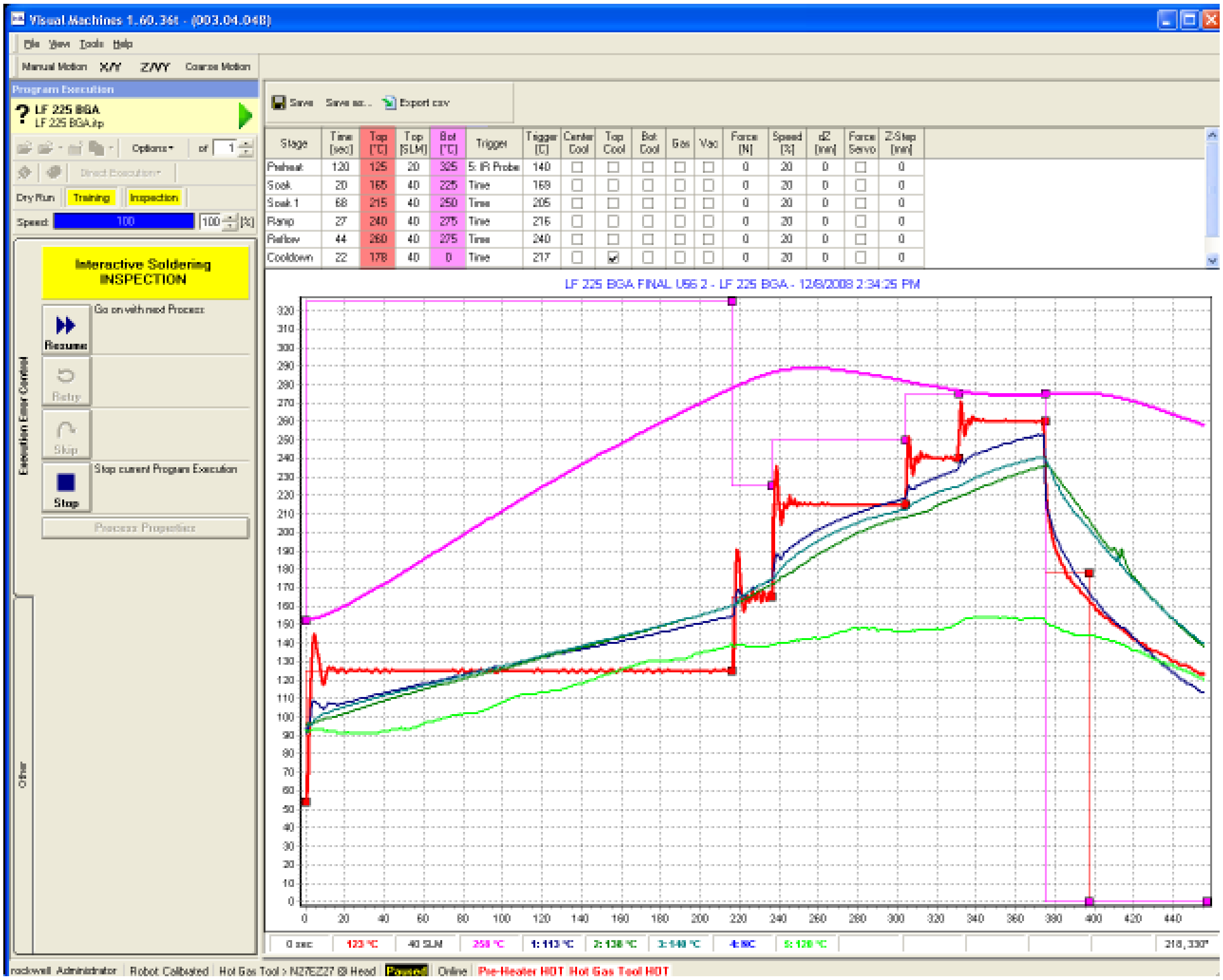


Figure 48 Lead-Free Rework Profile for BGA component, removal and replacement – Rockwell Collins

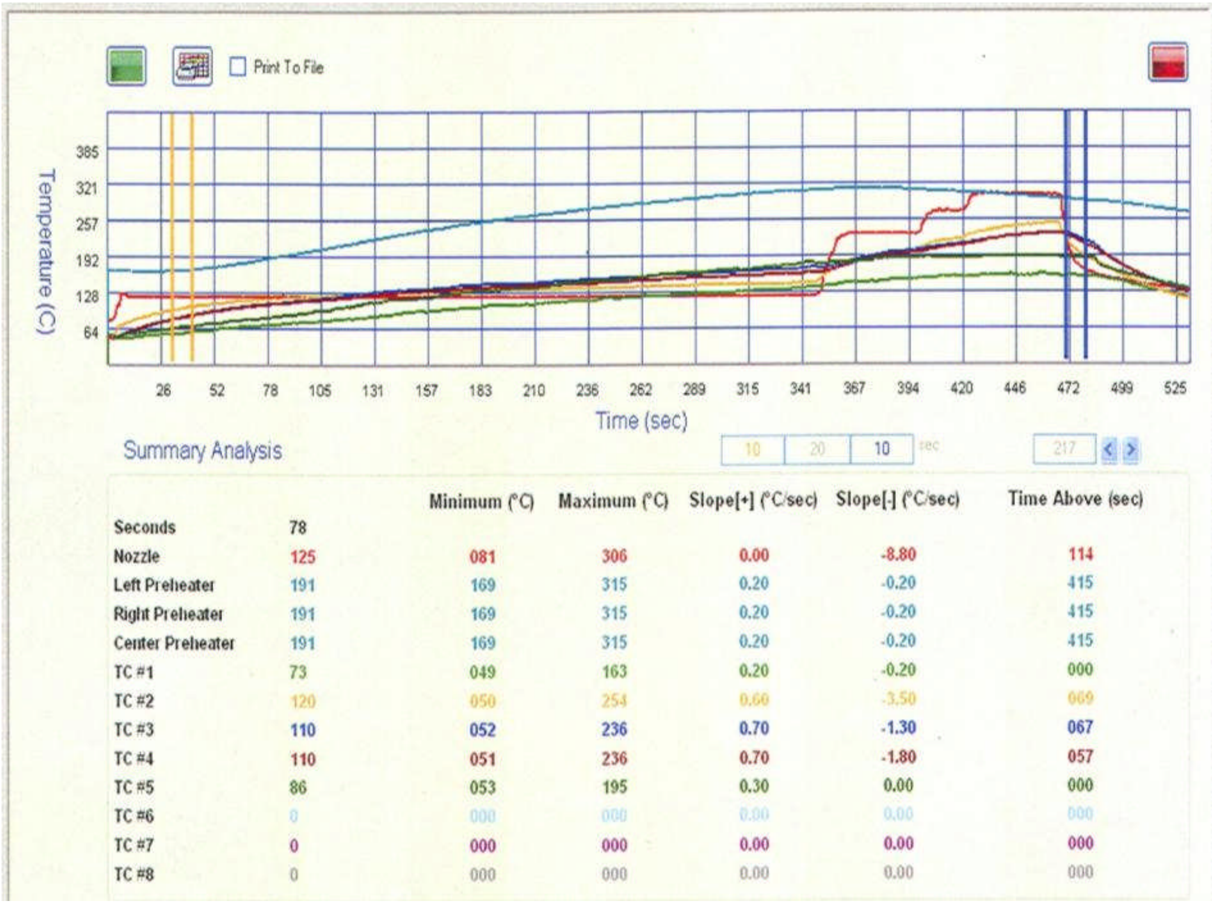


Figure 49 Lead-Free Rework Profile for CSP components, removal and replacement – BAE Systems

Table 39 Machine Settings for Rework Profiles – Lead-Free CSP – BAE Systems

	Nozzle	Preheater	Trigger point
Preheat	125	325	140 board
Presoak	225	200	169
Soak	235	200	205
Ramp	275	200	216
Reflow	305	200	235
Max board temp	163		
Max body	254		
Max ball	236		
Dwell	67 sec		

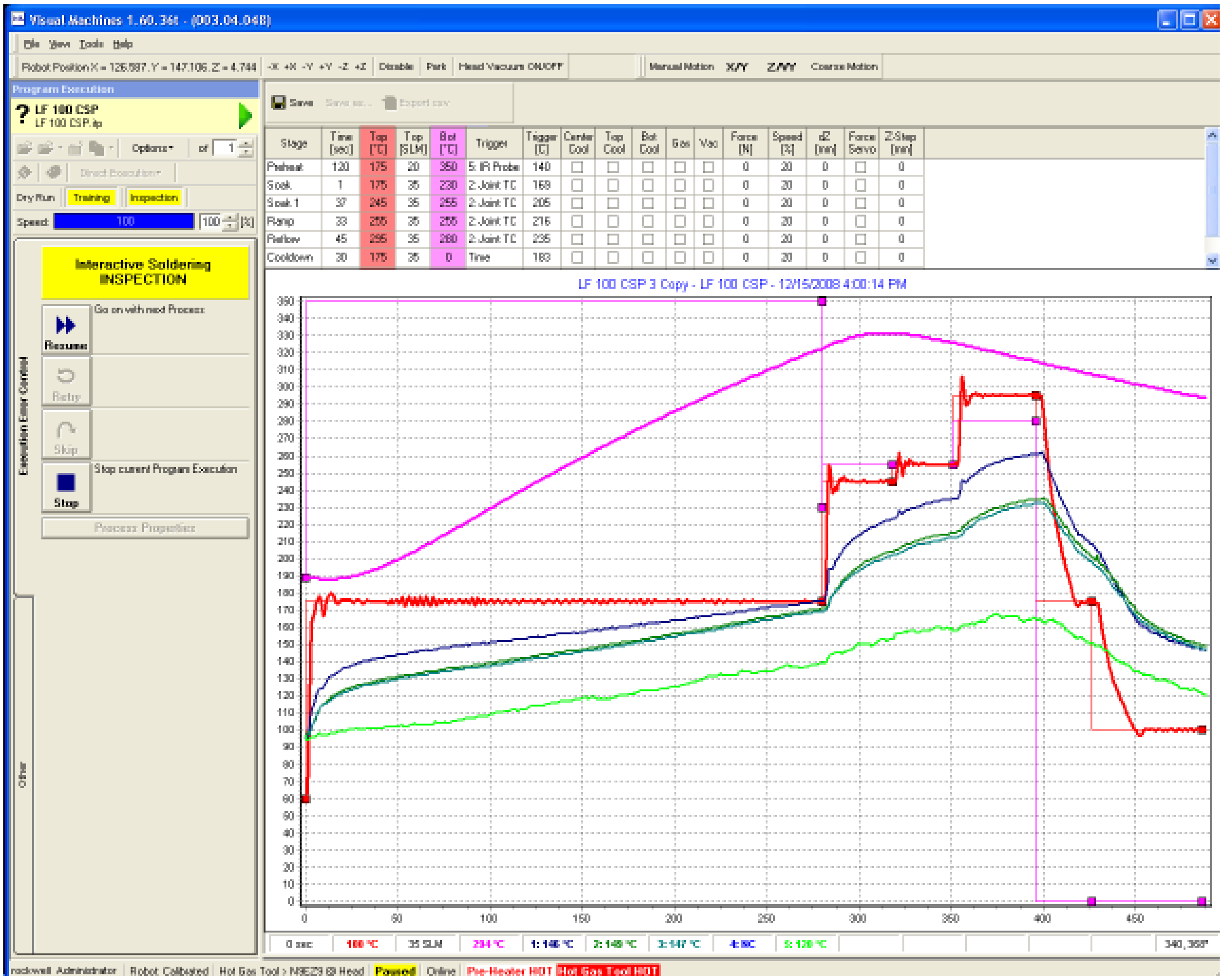


Figure 50 Lead-Free Rework Profile for CSP components, removal and replacement – Rockwell Collins

11.3 Component Rework Issue

During rework of the BGA components for Batch A (Lead-Free Rework) there were problems with loss of continuity for some of the reworked components. In an effort to rectify the loss of continuity, BAE Systems established the following sequence, accepted by the NASA-DoD LFE Project consortia:

- No continuity after initial rework:
  1. performed X-ray evaluations
  2. clean under the BGAs with IPA and air then test
  3. if IPA and air did not work, and there was evidence of partial melting or solder paste, the parts were left in place and reheated / reflowed again
  4. if blowholes on vias were found they were removed
  5. if removing the blowholes did not restore continuity, the BGA was removed and replaced with a new component

The NASA-DoD LFE Project consortia decided that the limit for reworks will be 3. If the continuity issue was not solved after 3 reworks, the components would be left on the test vehicles deemed non-functioning. All processes and procedures being completed during rework were tracked on the traveler that accompanies each test vehicle from assembly / rework through testing.

BGA components were not the only component type that had issues during rework. Table 40 to Table 44 show which components required multiple rework operations or required unscheduled rework operations.

Table 40 Component Rework Issue, Lead-Free Rework, BGA Components

Batch A - Lead-Free Rework - BGA Components								
Test	Test Vehicle	Component Location	Original Component Finish	Reflow Solder Alloy	New Component Finish	Rework Solder	Scheduled for Rework	Total # of Reworks
Mechanical Shock	SN189	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN189	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN189	U02	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN189	U21	SAC405	SAC305	SAC405	Flux Only	Yes	3
	SN189	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN190	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN190	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN190	U02	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN190	U21	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN191	U44	SnPb	SAC305			No	1
	SN191	U55	SnPb	SAC305			No	2
	SN191	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN191	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN192	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN192	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN192	U21	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN193	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN193	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN193	U02	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN193	U21	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN193	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2
Vibration	SN175	U04	SnPb	SAC305			No	1
	SN176	U43	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN177	U21	SAC405	SAC305	SAC405	Flux Only	Yes	3
	SN177	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2
Combined Environments	SN163	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN180	U02	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN180	U18	SAC405	SAC305	SAC405	SnPb	Yes	3
	SN180	U04	SnPb	SAC305			No	1
	SN180	U05	SnPb	SAC305			No	1
	SN180	U43	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN180	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN181	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN181	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN182	U21	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN183	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2
Drop Testing	SN184	U18	SAC405	SAC305	SAC405	SnPb	Yes	3
	SN184	U06	SAC405	SAC305	SAC405	SnPb	Yes	3
	SN184	U02	SAC405	SAC305	SAC405	Flux Only	Yes	3
	SN184	U21	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN184	U56	SAC405	SAC305	SAC405	Flux Only	Yes	3
	SN185	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN185	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN185	U02	SAC405	SAC305	SAC405	Flux Only	Yes	3
	SN185	U21	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN185	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN186	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN186	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN186	U21	SAC405	SAC305	SAC405	Flux Only	Yes	3
	SN187	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN187	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN187	U21	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN188	U18	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN188	U06	SAC405	SAC305	SAC405	SnPb	Yes	2
	SN188	U02	SAC405	SAC305	SAC405	Flux Only	Yes	2
	SN188	U21	SAC405	SAC305	SAC405	Flux Only	Yes	3
	SN188	U56	SAC405	SAC305	SAC405	Flux Only	Yes	2

Table 41 Component Rework Issue, Lead-Free Rework, CSP Components

Batch A - Lead-Free Rework - CSP Components								
Test	Test Vehicle	Component Location	Original Component Finish	Reflow Solder Alloy	New Component Finish	Rework Solder	Scheduled for Rework	Total # of Reworks
Thermal Cycle -55/+125°C	SN164	U19	SAC105	SAC305	SAC105	Flux Only	Yes	2
	SN164	U37	SAC105	SAC305	SAC105	Flux Only	Yes	2
	SN164	U50	SAC105	SAC305	SAC105	Flux Only	Yes	2
Drop Testing	SN185	U33	SAC105	SAC305	SAC105	SnPb	Yes	2

Table 42 Component Rework Issue, Lead-Free Rework, CLCC Components

Batch A - Lead-Free Rework - CLCC Components								
Test	Test Vehicle	Component Location	Original Component Finish	Reflow Solder Alloy	New Component Finish	Rework Solder	Scheduled for Rework	Total # of Reworks
Combined Environments	SN163	U45	SnPb	SAC305			No	2

Table 43 Component Rework Issue, SnPb Rework, BGA Components

Batch B - SnPb Rework - BGA Components								
Test	Test Vehicle	Component Location	Original Component Finish	Reflow Solder Alloy	New Component Finish	Rework Solder	Scheduled for Rework	Total # of Reworks
Mechanical Shock	SN152	U43	SnPb	SnPb	SAC405	SnPb	Yes	2
	SN153	U06	SnPb	SnPb	SAC405	SnPb	Yes	2
	SN160	U18	SnPb	SnPb	SAC405	SnPb	Yes	2
	SN160	U02	SnPb	SnPb	SnPb	Flux Only	Yes	2
	SN160	U21	SnPb	SnPb	SnPb	Flux Only	Yes	2
	SN160	U56	SnPb	SnPb	SnPb	Flux Only	Yes	2
Vibration	SN137	U18	SnPb	SnPb	SAC405	SnPb	Yes	2
	SN157	U21	SnPb	SnPb	SnPb	Flux Only	Yes	2
	SN157	U56	SnPb	SnPb	SnPb	Flux Only	Yes	2

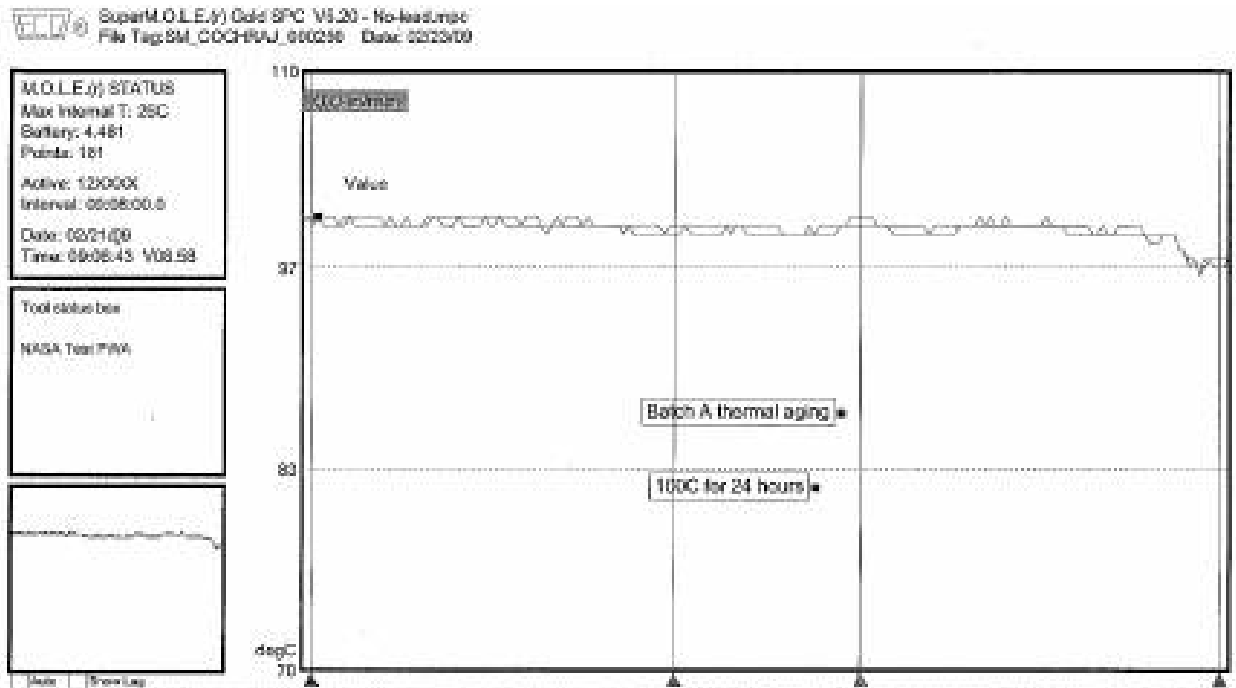
Table 44 Component Rework Issue, SnPb Rework, CSP Components

Batch B - SnPb Rework - CSP Components								
Test	Test Vehicle	Component Location	Original Component Finish	Reflow Solder Alloy	New Component Finish	Rework Solder	Scheduled for Rework	Total # of Reworks
Thermal Cycle -20/+80°C	SN133	U42	SnPb	SnPb	SAC105	SnPb	Yes	2

12.0 Thermal Aging, 100^{o}C for 24 hours

The project consortia members reviewed intermetallic calculations generated by Rockwell Collins and compared the calculations to data sets from the Center for Advanced Vehicle Electronics (CAVE) at Auburn University, the National Physics Laboratory (NPL), the National Institute of Standards and Technology (NIST), and the Center for Advanced Life Cycle Engineering (CALCE) at University of Maryland. The thermal aging procedure was selected to establish a common, standard starting point such that all test vehicles were relatively equal in terms of solder joint microstructure, printed wiring board stress state, surface finish oxidation condition, and intermetallic phase formation/thickness. The project consortia members desired to have the test vehicles begin the various testing procedures with a common starting state point in an effort to eliminate potential assembly differences which could possibly inadvertently/unintentionally influence the testing results. The thermal aging procedure is not necessarily, nor intended to be, representative of the various burn-in, bake-out, or other environmental stress screening (ESS) procedures that are used to evaluate electronics hardware quality/functionality. Additionally, it should be noted that the thermal aging procedure being used by the NASA-DoD LFE Project consortia is not meant to be representative of operational field life. A wide range of ESS procedures and operational field expectations exist in the high performance electronics industry, from telecom applications to space applications, thus an industry consensus "standard" thermal aging procedure that fits all electronics users is not available.

Test vehicle Batches B, F and I were exposed to extended thermal aging, 4 days, instead of 24 hours.



Value	C1 = 00:16:00r	C2 = 09:36:00r	C3 = 14:24:00r	C4 = 23:44:00r	Units
Center of laminate	99	99	99	97	degC
Outside edge	100	99	100	97	degC
open					
Open					
Open					
open					

T Above Ref	Low = 149	Med = 180	Hi = 230	Cure Factor	Units
Center of laminate	00:00:00	00:00:00	00:00:00	0%	Time
Outside edge	00:00:00	00:00:00	00:00:00	0%	Time
open					
Open					
Open					
open					

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
Center of laminate	96	23:12:00r	100	00:08:00r	99.1	0.6	degC
Outside edge	96	23:12:00r	100	00:00:00r	99.4	0.6	degC
open							
Open							
Open							
open							

Figure 51 Thermal Aging Profile

13.0 Assembly Irregularities

With all of the complexities built into the NASA-DoD Lead-Free Electronics Project design of experiment, test vehicle irregularities are bound to occur. Following are two test vehicle irregularities that affect the collection of data from the test vehicles.

13.1 Chip Scale Package (CSP)

When reviewing the CSP data, please note that the CSP components on all test vehicles only have continuity in the outside solder balls. The wrong component configuration was used during test vehicle drafting. Traces interconnecting internal rows of balls to the outside row of balls do not exist on the test vehicles, Figure 52. In order for a CSP component failure to be recorded, breaks in both sides of the continuity box must occur, Figure 53.

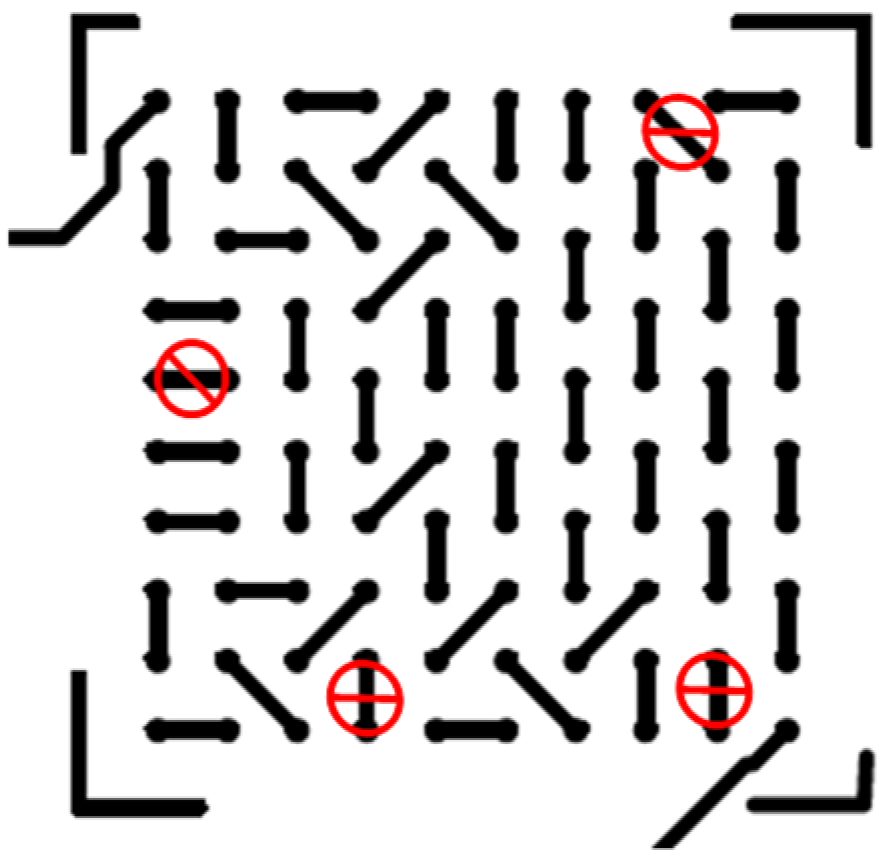
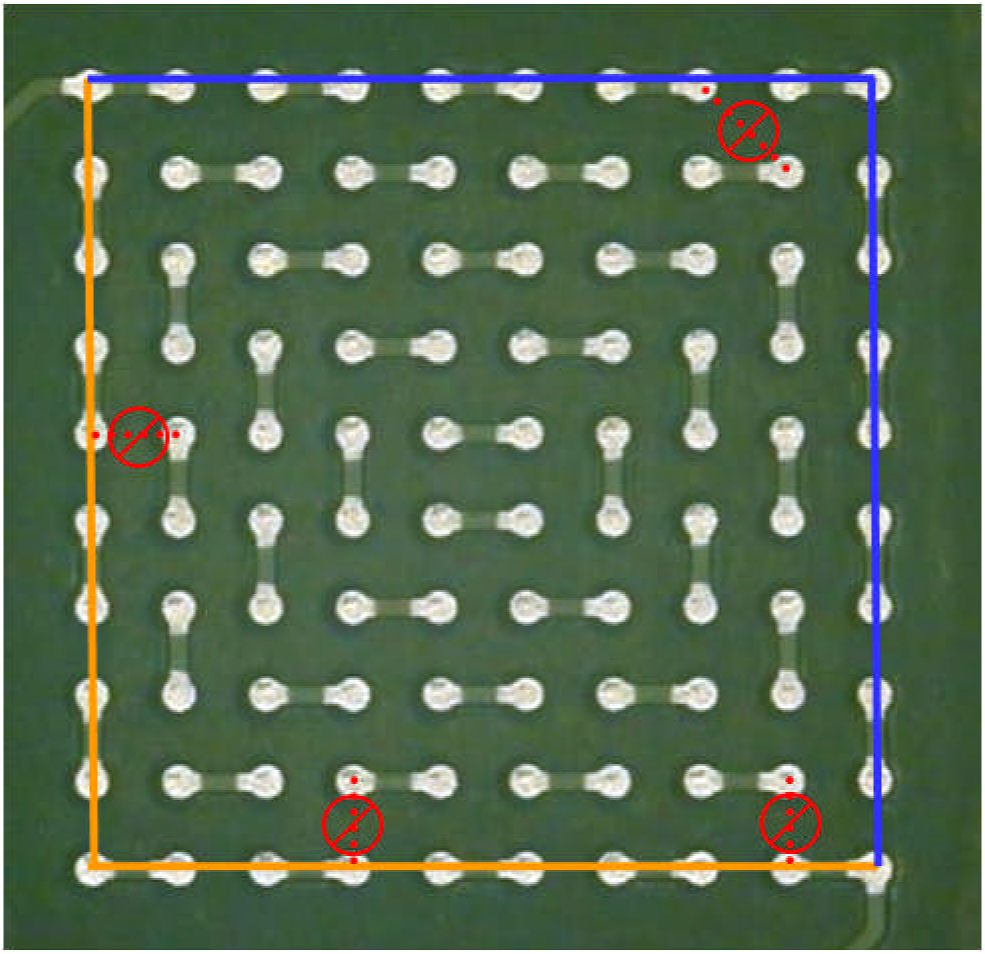


Figure 52 Test Vehicle Drawing, Chip Scale Package (CSP)



[Figure](#) 53 Chip Scale Package (CSP) Continuity Loop

13.2 Quad Flat No leads (QFN), Location U15

Component location U15, a QFN, is missing a wire trace, Figure 54. During drafting, the trace was not included in the test vehicles drawing, Figure 55. Test data cannot be collected for this component unless a jumper wire is used in-place of the missing trace. Jumper wires were used for the thermal cycle test vehicles. For vibration, drop, mechanical shock and combined environments testing, it was determined that a jumper wire is not feasible. For the NSWC Crane rework test vehicles, QFN U15 is an active rework component. For drop and vibration testing, a jumper wire will be attached to each U15 location to permit collection of test data.

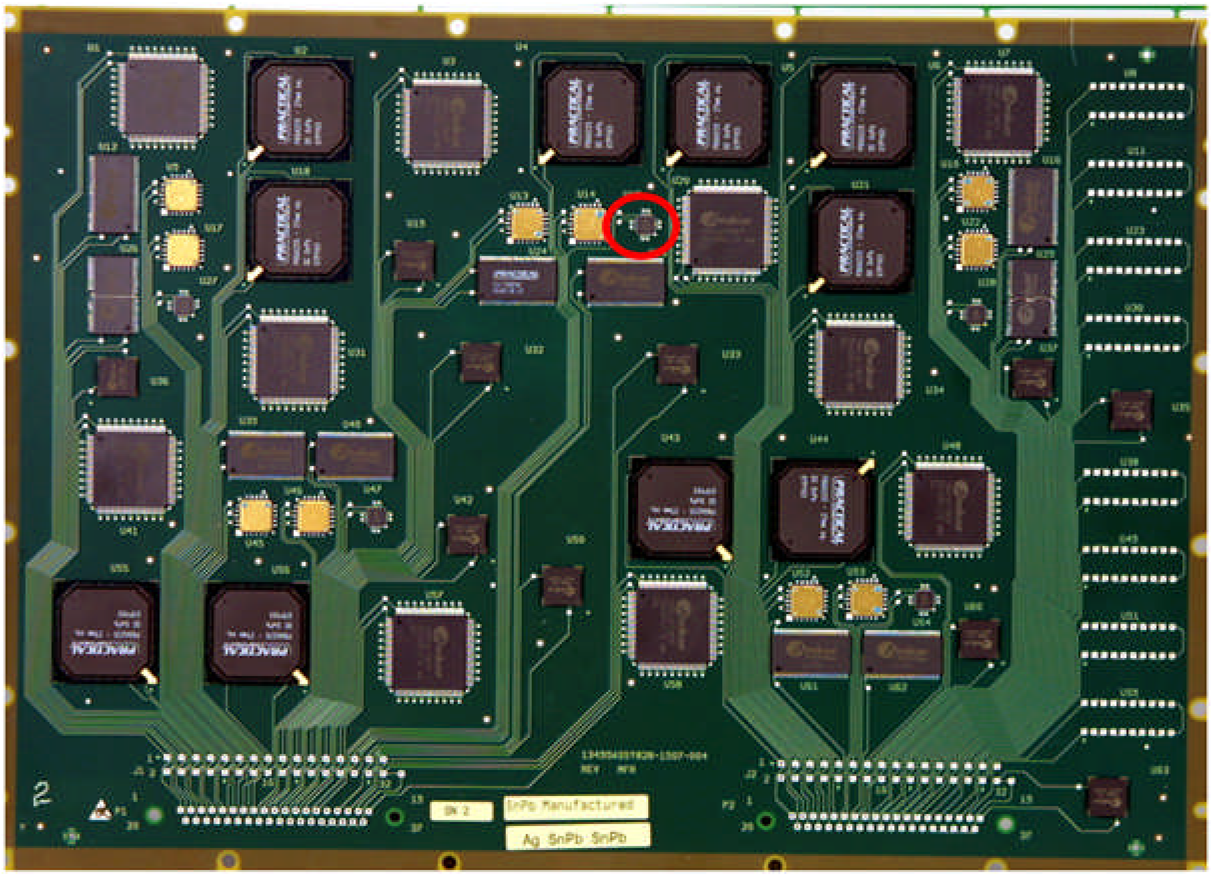


Figure 54 Quad Flat No leads (QFN), Component Location U15

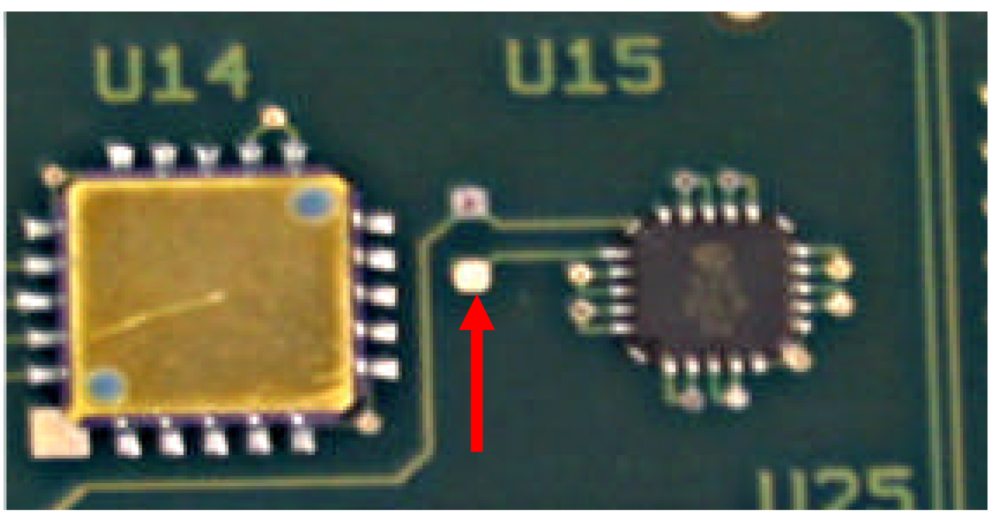


Figure 55 Missing Trace, QFN – U15

14.0 Rework Test Vehicle Characterization

Following assembly and rework procedures, Rockwell Collins will cross-section the rework test vehicles set aside for characterization. One component from each of the 4 component types (BGA, CSP, PDIP, TSOP) being reworked from each of the 3 types of rework boards (SnPb, SnPb-ENIG, lead-free) will be cross sectioned.

Table 45 Rework Test Vehicles for Characterization

Project Activity	Batch / Board Number
Test Vehicle Characterization	Batch A / SN163
	Batch B / SN123
	Batch B / SN154

15.0 Testing Activities

The first step in developing the test plan was to review the performance requirements called out in applicable military and industry standards, and then select test methods recognized and agreed upon by the technical team members. A key factor was selecting test parameters that would subject enough environmental stress to cause solder joints to fail, thus permitting differentiation between lead vs. lead-free performance. Military document MIL-STD-810F and industry documents IPC-SM-785 and IPC-TM-650 were primary references used for writing the test plan. One test—the Combined Environments test—followed a procedure developed and used by Raytheon.

15.1 Vibration

The vibration test determines solder joint failures during exposure to vibration conditions. The stakeholders agreed that MIL-STD-810F, Method 514.5 (Vibration), would be the starting point for developing a vibration test that would determine the reliability of the various solder alloys under severe vibration. Specific details on the vibration test can be found in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

15.2 Thermal Cycling

The thermal cycle testing determines the capability of a solder to withstand extreme thermal cycling. This test will be performed in accordance with IPC-SM-785 *(Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments)*.

Thermal cycling will be conducted at two different conditions, -55 to +125°C and -20 to +80°C, technical representatives from the U.S. Army Aviation and Missile Command (AMCOM) suggested two temperature ranges to allow for acceleration factors to be determined, which will permit extrapolation of the data to actual use conditions of their systems. The thermal cycle tests will be run until a significant number (greater than 63 percent) of component failures are achieved in order to provide statistically meaningful data. Specific details on the thermal cycle test can be found in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

15.3 Mechanical Shock

The purpose of the mechanical shock test is to determine the resistance of the solder to the stresses associated with high-intensity shocks induced by rough handling, transportation, or field operation. The mechanical shock test procedure was changed from the procedure used for the JCAA/JGPP Lead-Free Solder Project. The consortia members felt that the procedure change was necessary since it is very difficult to meet both the SRS shape and the pulse duration for this test as outlined in MIL-STD-810F. Pulse duration is approximately equal to the inverse of lowest SRS frequency, 10 Hz. SRS requirement means pulse duration >100 msec while MIL-STD-810F outlines pulse durations $\leq$ 23 msec. Additional details on the procedure change are contained in Appendix E. Specific details on the mechanical shock test can be found in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

15.4 Combined Environments Test

The Combined Environments Test (CET) determines the reliability of solders under combined thermal cycle and vibration. The CET for the lead-free solder project is based on a modified Highly Accelerated Life Test (HALT), a process in which products are subjected to accelerated environments to find weak links in the design and/or manufacturing process. The project stakeholders felt that the CET would provide a quick method to identify comparative potential reliability differences in the test alloys vs. the SnPb baseline. The primary accelerated environments are temperature extremes (both limits and rate of change) and vibration (pseudo-random six degrees of freedom used in combination). Specific details on the combined environments test can be found in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

15.5 Drop Testing

This test determines the resistance of board level interconnects to board strain induced by dynamic bending as a result of drop testing. Boards tested using this method typically fail either as interfacial fractures in the solder joint (most common with ENIG) or as pad cratering in the component substrate and/or board laminate. These failure modes commonly occur during manufacturing, electrical testing (especially in-circuit test), card handling and field installation. The root cause of these types of failures is typically a combination of excessive applied strain due to process issues and/or weak interconnects due to process issues and/or the quality of incoming components and/or boards. Specific details on the drop test can be found in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

15.6 Interconnect Stress Test (IST)

IST is an industry recognized test method (IPC) that accelerates thermal cycling testing by heating a specifically designed test coupon to 150°C in exactly 3 minutes followed by cooling to ambient in approximately two minutes. IST test coupons have two circuits, a sense circuit and a power circuit, to monitor material delamination and crazing. The power circuit heats the coupon. The sense circuit is a passive circuit that monitors temperature and measures damage accumulation of the interconnect structure, typically a plated through-hole (PTH). There are usually 400 to 800 structures per circuit to achieve a higher, statistically relevant, sample size. Both the power and sense circuits changes in resistance (milliohms) and temperature (°C) throughout the coupons during the thermal cycle. Thermal cycling continues until end of test or a 10% increase in resistance on either circuit. Each coupon is heated, monitored, and tested individually. This gives a number of advantages that include no hold time at temperature, tight test control in the ability to achieve any test temperature in three minutes +/- 5 seconds, the ability to stop testing within seconds of the circuit achieving a 10% increase in resistance allowing analysis of a developing failure rather than a catastrophic failure. Testing stops immediately when the circuit achieves 10% increase in resistance, allowing a failed circuit to have a low amount of power applied that creates a hot spot at the failure site visible by a thermal imaging camera. Specific details on IST can be found in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

15.7 Copper Dissolution

The purpose of the copper dissolution testing is to characterize, document, and compare the impact of soldering process on the copper plated through-hole and surface pad structures for the NASA-DoD test vehicles with the SAC305 and SN100C solder alloy systems. The copper dissolution test results will provide a data set which can be used as a first order approximation of the copper plating thickness loss due to lead-free solder processing. Additionally, the copper dissolution test results can be compared to other published industry results for alternative solder alloy systems and different soldering processes.

Printed Circuit Board (PCB) land and plated through-holes can be eroded or dissolved away in the presence of molten solder rendering the PCB non-functional. Significant dissolution can occur with the use of certain new Sn-rich alloys and is further exacerbated by higher process temperatures. Clearly this phenomenon represents a serious risk to circuit reliability. There is a clear need to determine the dissolution rate of copper pads with lead-free solders under various conditions. Specific details on copper dissolution can be found in the JTP, "*NASA-DoD Lead-Free Electronics Project, Joint Test Protocol; September 2009*".

16.0 Failure Analysis

The purpose of the failure analysis is to identify the failure mode and the most probable failure mechanism of the solder joints. Accordingly, solder alloy material integrity, composition, microstructure and metallurgical features specific to the type of alloy shall be investigated on all types of boards, hence all types of solders and termination finishes.

Failure analysis will be performed per the procedure outlined in 16.1 and will encompass visual, x-ray, micro-structural evaluation, and composition on a selected sampling of failed joints of components identified and recorded during stress testing.

In order to assure that metallurgical characteristics are relevant to the failure, reference samples of joints not detected as failed will also be evaluated. The reference samples (joints) will be selected from the same component. PCB pad condition and overall board material integrity condition at the failed component shall be evaluated as well.

16.1 Procedure

Failure analysis will not be done until all testing to any given environment is completed. Components will not be removed from the test vehicles during testing.

16.1.1 Sample Identification

Failure analysis procedure shall be performed per Figure 56. Components are identified by the following set of symbols:

1. PCB Number
2. Component type and reference designator for the assigned location on PCB.
   Example: U18
3. Table number
   Example: “Table 7”; the table number from this document that lists component finish and solder type applied for attachment or rework. Identification number of failed solder joint/termination number as identified from the data sheet of the part, or UK (unknown) if the failed part termination or solder joint cannot be identified prior to cross-sectioning.
4. Acronym defining type of test the board was exposed to such as:
   - TC (Thermal Cycling)
   - CE (Combined Environments)
   - V (Vibration)
   - MS (Mechanical Shock)
   - DT (Drop Test)

The component solder joint location, material composition and testing history will be defined by the following set of symbols:

- **Example One: 1-BGA-U18-07-1-TC**

It translates into PCB Number 1, component BGA at the location U18, Table 7, failed pin solder joint number 1 and, post thermal cycling. In addition Table 7 specifies SAC405 as component finish and SAC305 reflow solder.

- **Example Two: 1-BGA-U18-07-UK-TC**

It translates into PCB Number 1, component BGA at the location U18, Table 7, failed pin solder joint not identifiable and, post thermal cycling. In addition Table 7 specifies SAC405 as component finish and SAC305 reflow solder.

16.1.2 Sample Size

The minimum number of components for failure analysis will be determined by the project stakeholders on test by test basis.

In the case where no components are identified as failed, a destructive physical analysis (DPA) will be performed. Procedures for DPA will be identical to the FA procedure specified in Figure 56. Statistical analysis of the test vehicle failure data for each test shall be used to identify potential candidate components for FA and DPA analysis. A minimum of 3 failed and 3 non-failed samples shall be analyzed from each of seven component types (BGA-225, CLCC-20, CSP-100, PDIP-20, QFN, TQFP-144, TSOP-50), from the SnPb and lead-free Manufactured test vehicles as well as the SnPb and lead-free Reworked test vehicles. For each component type (BGA-225, CLCC-20, CSP-100, PDIP-20, QFN, TQFP-144, TSOP-50), one of the 3 (minimum number) failed samples should be the last component to fail. All “outlier” test vehicle component failures, as determined by the statistical analysis, shall be analyzed. Additional samples (failed or non-failed) may be from the test vehicles and those results shall be included in the FA/DPA report.

Table 46 Example Failure Analysis Tracking Table (Batch C)

SnPb Manufactured: SN__________										
Component	Component Finish	Reflow Solder	Wave Solder	Board Finish	Sample Identification					
					Failed			Non-Failed		
BGA-225	SAC405	SnPb								
BGA-225	SnPb	SnPb								
CLCC-20	SAC305	SnPb								
CLCC-20	SnPb	SnPb								
CSP-100	SAC105	SnPb								
CSP-100	SnPb	SnPb								
PDIP-20	NiPdAu		SnPb	Immersion Ag						
PDIP-20	Sn		SnPb							
QFN	Matte Sn	SnPb								
TQFP-144	Matte Sn	SnPb								
TQFP-144	SnPb Dip	SnPb								
TSOP-50	SnBi	SnPb								
TSOP-50	SnPb	SnPb								

Table 47 Example Failure Analysis Tracking Table (Batch B)

SnPb Rework: SN__________												
Component	Component Finish	Reflow Solder	Wave Solder	New Component Finish	Rework Solder	Board Finish	Sample Identification					
							Failed			Non-Failed		
BGA-225	SAC405	SnPb		--	--	Immersion Ag						
BGA-225	SnPb	SnPb		SAC405	SnPb							
BGA-225	SnPb	SnPb		SnPb	Flux Only							
CLCC-20	SAC305	SnPb		--	--							
CSP-100	SAC105	SnPb		--	--							
CSP-100	SnPb	SnPb		SAC105	SnPb							
CSP-100	SnPb	SnPb		SnPb	Flux Only							
PDIP-20	NiPdAu		SnPb	--	--							
PDIP-20	Sn		SnPb	--	--							
PDIP-20	SnPb		SnPb	Sn	SnPb							
QFN	Matte Sn	SnPb		--	--							
TQFP-144	NiPdAu	SnPb		--	--							
TQFP-144	SnPb Dip	SnPb		--	--							
TSOP-50	SnBi	SnPb		--	--							
TSOP-50	SnPb	SnPb		--	--							
TSOP-50	SnPb	SnPb		SnPb	SnPb							
TSOP-50	SnPb	SnPb		Sn	SnPb							

16.1.3 FA/DPA Component Preparation

Components on intact test vehicles

1. Component identification/labeling with labels as specified in 16.1.1
2. Visual evaluation of the component body and solder joints material integrity.
3. An overall photo of the test vehicle capturing component location / orientation is required
4. Photographing typical appearance of the failed and non failed solder joints
    a. Photographs of disturbed component trends
    b. Magnifications should be recorded by the FA / DPA facility
    c. The analyst has the freedom to chose the proper micrograph to reveal the anomaly or region of interest found at a particular magnification
5. X-Ray evaluation of the test vehicles and failed/non-failed solder joints shall be conducted. The X-Ray equipment and technique shall be identified in the FA/DPA report.
    a. The analyst has the freedom to choose the proper micrograph to reveal the anomaly or region of interest.
6. Thermal imaging for identification of failed solder joints not identifiable by visual or x-ray techniques may also be conducted if the necessary resources are available. The thermal imaging equipment and technique shall be identified in the FA/DPA report.
7. For array components (BGA and CSP) characterize corner and die-shadow joints. This can be done by metallographic cross-section or dye and pry.

Following the evaluation of the components they will be removed from the test vehicles in accordance with ASTM E3.

1. Suggested metallographic analysis procedure:
    a. Each component with failed solder joint shall be positioned into a mould in orientation perpendicular to the grinding plane and potted in a two part 24 [h] epoxy (Buehler Epo-resin and Epo-hardener). Grinding will be performed by the following technique: 180 grit, 240 grit, 400 grit, 800 grit, and 1200 grit. Polishing by 6 [μ] diamond and 0.05 [μ] alumina.
    b. Colloidal silica is highly recommended for final polishing

16.1.4 Analysis

FA and DPA procedures shall be performed per Figure 56. The statistical analysis of the test vehicles shall be provided by the testing organization/facility to the FA/DPA facility. Additional failed and non-failed components above the stated minimums may be done by the cognizant FA/DPA facility.

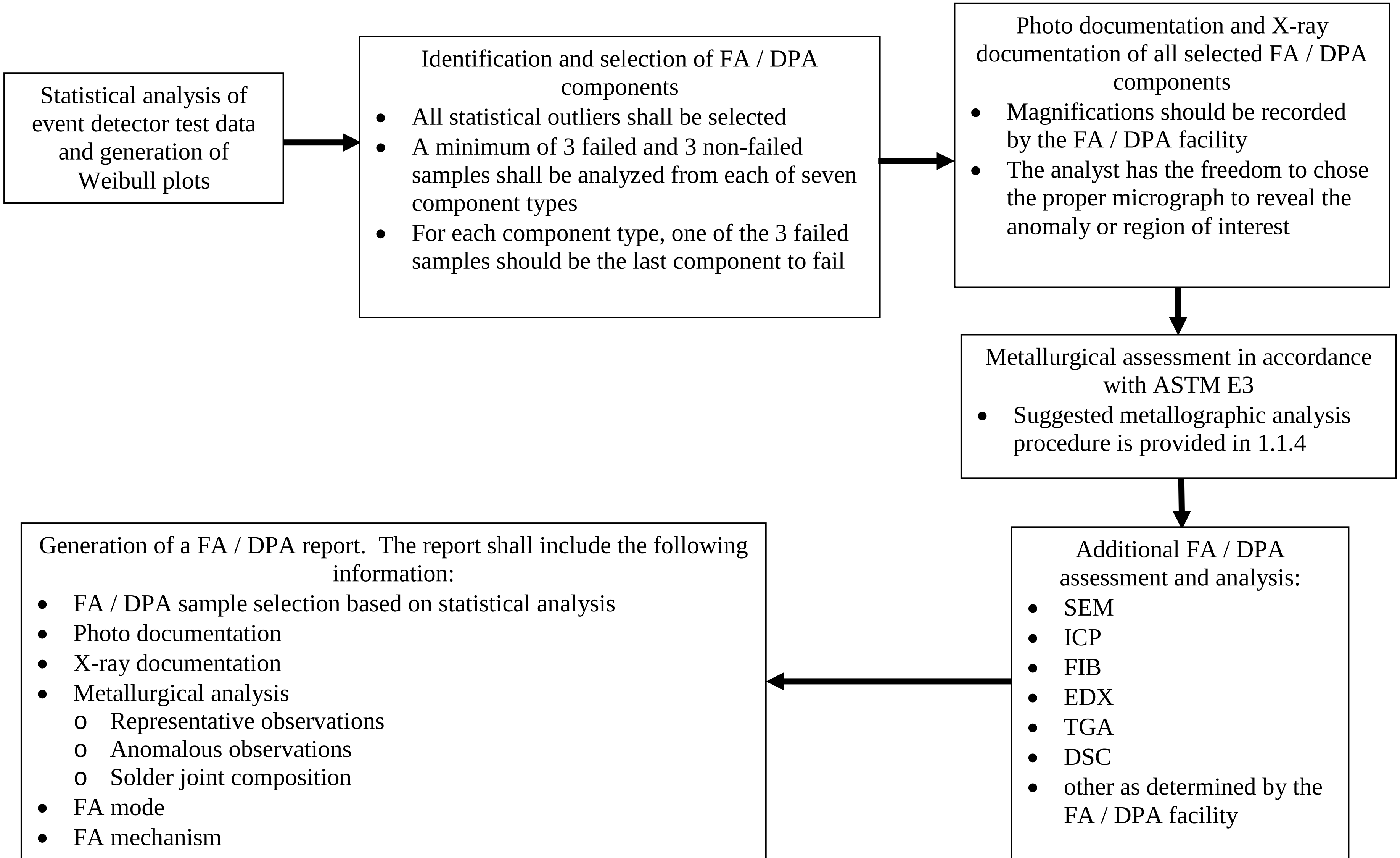


Figure 56 Failure Analysis Procedure

17.0 References

1. P. Snugovsky, A. R. Zbrzezny, M. Kelly, M. Romansky, “Theory and Practice of Lead-Free BGA Assembly Using Sn-Pb Solder”, Lead-Free Conference, CMAP Toronto, May 2005.
2. D. Hillman, M. Wells, K. Cho, “The Impact of Reflowing A Pbfree Solder Alloy Using A Tin/Lead Solder Alloy Reflow Profile On Solder Joint Integrity”, Lead-Free Conference, CMAP Toronto, May 2005.

- IPC 6012B: Qualification and Performance Specification of Printed Circuit Boards August 2004
- IPC 45101B: Specification for Base Materials for Rigid and Multilayer Printed Boards
- MIL-STD-810F: Environmental Engineering Considerations and Laboratory Tests January 2000
- IPC/EIA J-STD-001C: Requirements for Soldered Electrical and Electronic Assemblies March 2000
- IPC SM 785: Guidance for Accelerated Reliability Testing of Surface Mount Solder Attachments Nov. 1992
- IPC-9701: Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments February 2006
- IPC TM 650:
- NASA STD 8739.2: Workmanship Standard for Surface Mount Technology
- IPC 9252: Guidelines and Requirements for Electrical Testing of Unpopulated Boards, Jan 2001
- ANSI/J-STD-003: Solderability Test for Printed Boards
- IPC-2221: Generic Standard on Printed Board Design
- IPC-2222: Sectional Design Standard for Rigid Organic Printed Boards
- IPC-A-610D: Acceptability of Electronic Assemblies
- IPC-4101B: Specification for Base Materials for Rigid and Multilayer Printed Boards
- IPC-7711: Rework of Electronics Assemblies

Appendix A – TSOP components without dummy die

One of the dominate failure modes of solder joints in the electronics industry is the loss of solder joint integrity due to coefficient of thermal expansion (CTE) mismatch. The typical printed wiring board is an epoxy laminate material with a CTE of 16 ppm/°C, the CTE of a component silicon die is 6 ppm/°C, the CTE of copper is 16 ppm/°C and the CTE of eutectic tin/lead solder that comprises a solder joint is 24 ppm/°C. Reviewing the differences in CTE values reveals that there is a local CTE mismatch between the printed wiring board and the component with the solder joint taking the brunt of the thermally induced dimensional changes. The impact of CTE mismatch on a solder joint can be demonstrated as a worst and best case scenario for two component types: Leadless Ceramic Chip Carriers (LCCC) and Quad Flat Packs (QFP). An LCCC is a ceramic bodied component with solder connections directly to the printed wiring board without the benefit of a compliant lead. An LCCC has a CTE of 6 ppm/°C and the epoxy laminate printed wiring board a CTE of 16 ppm/°C – a significant CTE mismatch which results in the severe degradation of solder joint integrity and is the worst case example. A QFP is a plastic bodied component with a compliant lead construction. A QFP has a CTE of 16 ppm/°C, the copper lead a 16 ppm/°C, the eutectic tin/lead solder a 24 ppm/°C and the epoxy laminate printed wiring board a CTE of 16 ppm/°C – a relatively matched CTE set of materials which does not result in severe degradation of solder joint integrity and is the best case example. The inclusion of dummy silicon die in many components is an important factor in replicating solder joint degradation due to CTE mismatch conditions.

The NASA-DoD Lead-Free Electronics Project included a thin small outline package (TSOP) which utilized an iron/nickel leadframe material instead of the typical copper leadframe material. The TSOP component configuration was selected because the iron/nickel leadframe material, with a CTE of 6 ppm/°C, induced the same severe solder joint degradation as a ceramic bodied component but in a more widely industry utilized package type. The iron/nickel leadframe material CTE mismatch induced solder joint degradation is very useful in terms of DOE investigation failure benchmarking. The NASA-DoD Lead-Free Electronics Project consortia was confronted with a component procurement issue for the TSOP components due to daisy chain configuration problem. A source of TSOPs was found with an acceptable daisy chain configuration for testing. Unfortunately, the acceptable daisy chain TSOPs did not contain a dummy silicon die. However, the iron/nickel leadframe material induced CTE mismatch is the dominate CTE mismatch driving force in comparison to the dummy silicon die induced CTE mismatch for the TSOP component. Other industry investigations [1-3] have demonstrated this parameter influence for the TSOP component with iron/nickel leadframe. The NASA-DoD Lead-Free Electronics Project consortia proceeded with the procurement of the TSOP components without dummy die for the investigation based on this component assessment.

References:

1. J. Lau, S. Golwalkar, P. Boysan, R. Surratt, R. Forhringer, S. Erasmus, “Solder Joint Reliability of a Thin Small Outline Package (TSOP)”, Circuit World, Volume 20, Number 1, 1993.

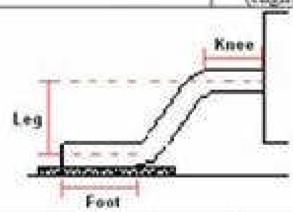
2. W. Engelmaier and B. Fuentes, “Alloy 42- A Material to be Avoided for Surface Mount Component Leads and Lead Frames”, Soldering & Surface Mount Technology, Volume 21, October, 1995.

3. J. Lau and Y. Pao, Solder Joint Reliability of BGA, CSP, Flip Chip, and Fine Pitch SMT Assemblies, ISBN 0-07-036648-9, McGraw Hill, 1997, page 329-356.

Appendix B – Example Component Characteristic Worksheet

Package:

Feature	Value
Package length	metric mm (english inch)
Package width	metric (english)
Package thickness	metric (english)
Pitch	metric (english)
Mass	g
CTE (Moire method for BGA & CSP, otherwise TMA method)	ppm/°C
Die length	metric (english)
Die width	metric (english)
Die thickness	metric (english)
Lead width	metric (english)
Lead thickness	metric (english)
Minimum lead gap	metric (english)



Lead foot length	metric (english)
Lead leg length	metric (english)
Lead knee length	metric (english)

Feature	Value
Lead/Termination Base Metal Alloy	Alloy
Lead/Termination Metallization / thickness	Alloy/metric (english)
Plating 1 metallization / thickness	Alloy/metric (english)
Plating 2 metallization / thickness	Alloy/metric (english)
Plating 3 metallization / thickness	Alloy/metric (english)
Over-plate to protect during cross section?	yes/no, plating
Diameter of solder balls	metric (english)
Solder ball alloy (SEM or XRF estimate)	
Width of solder ball in contact w/ component pad	metric (english)
Width of component pad	metric (english)
Thickness of component pad	metric (english)
Diameter of solder mask opening	metric (english)
Daisy chain pattern has been confirmed (daisy chain even pattern: 1-2, 3-4, etc.)	yes/no

Insert image here and resize if necessary
X-ray

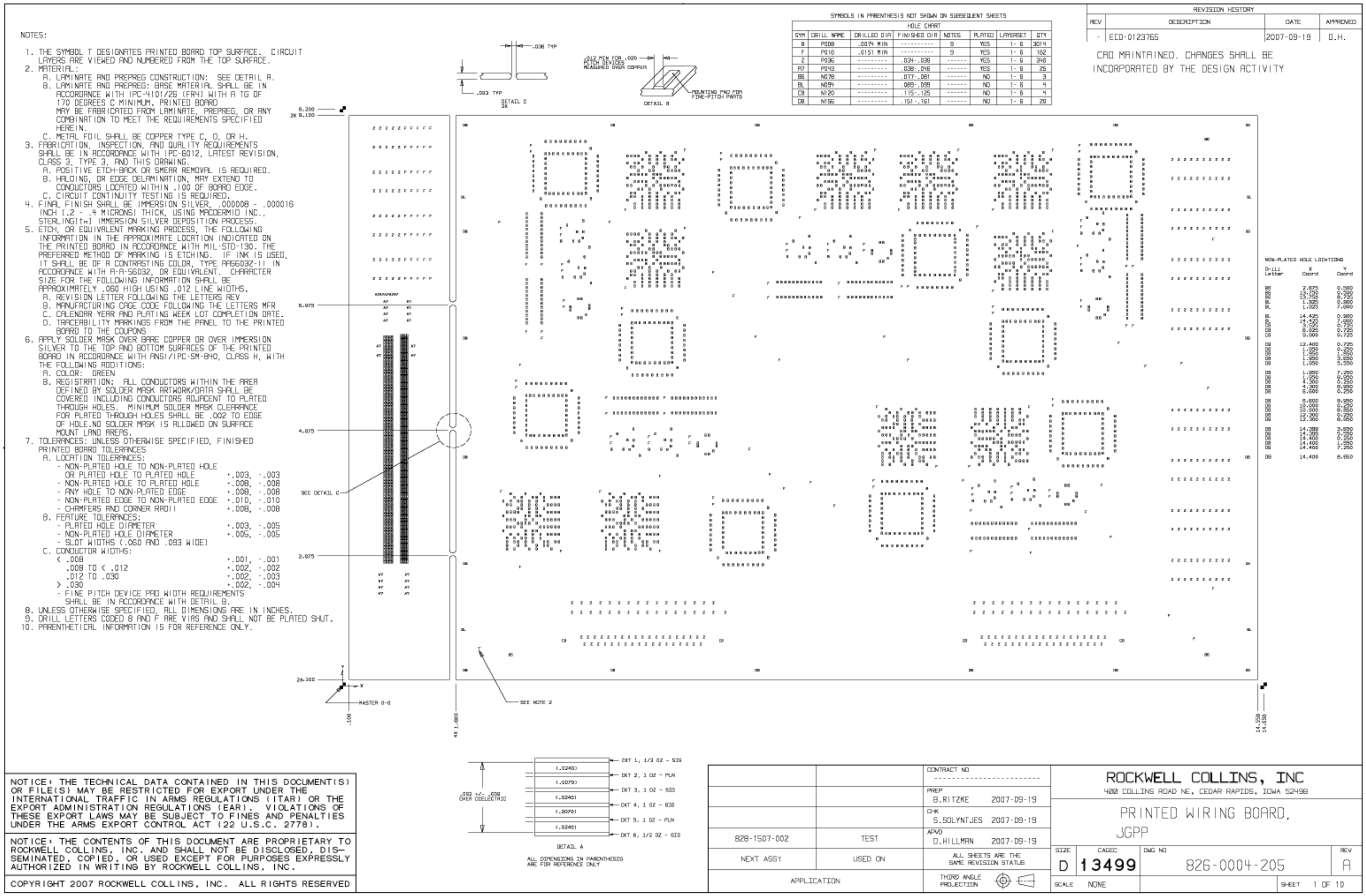
Insert image here and resize if necessary
Top View

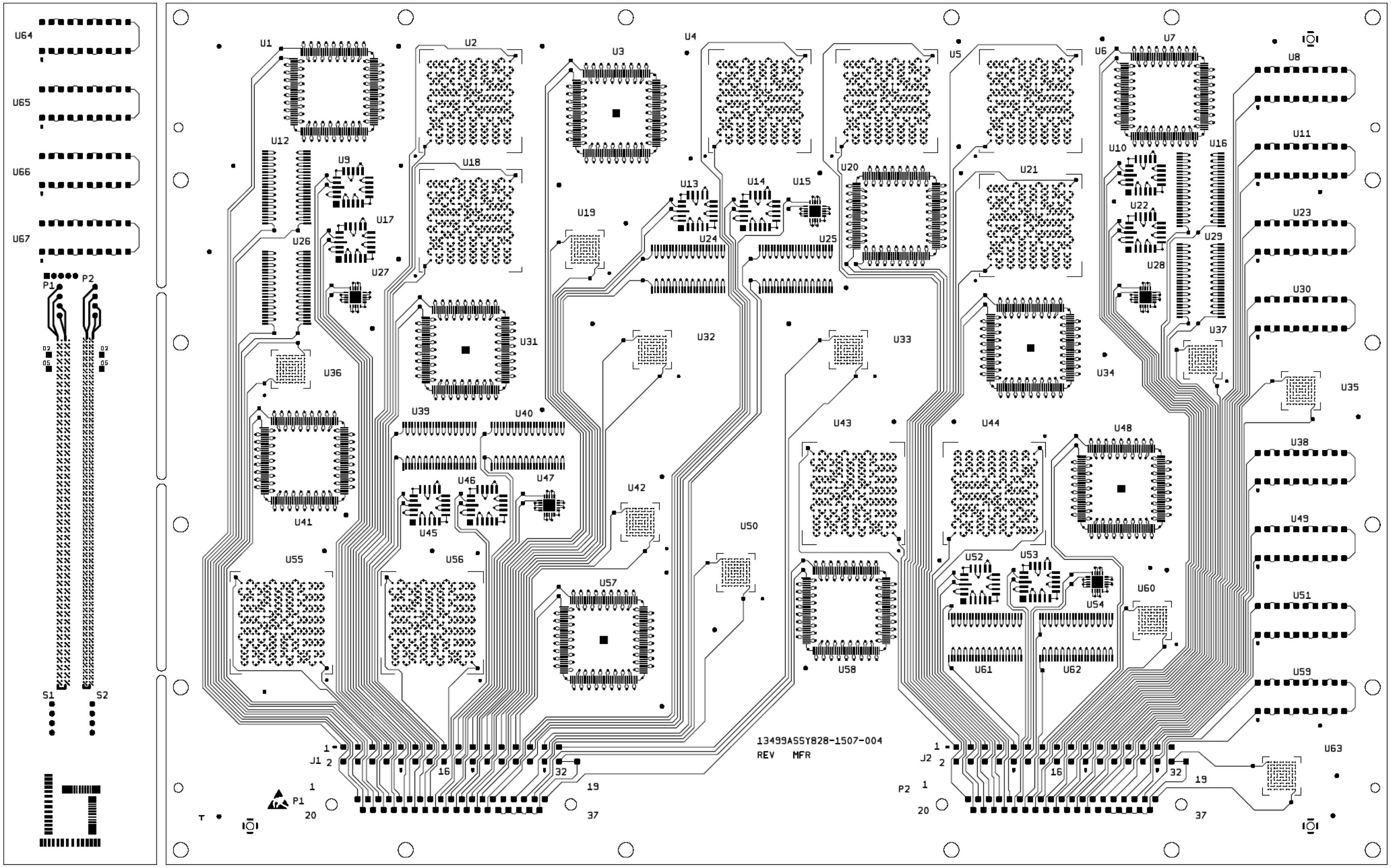
Insert image here and resize if necessary
End View/Bottom View

Insert image here and resize if necessary
Cross-section of (fill in mag hereX)

Insert image here and resize if necessary
SEM of cross-section

Appendix C – Test Vehicle Drawings

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Appendix D – NAVSEA Crane Assembly and Rework Effort

Crane Division, Naval Surface Warfare Center, a NASA-DOD Consortium member, is adding 30 test vehicles to the NASA-DOD study in support of their Naval Supply Command (NAVSUP) sponsored "Logistics Impact of Lead-Free Circuits/Components" project**.**

The NAVSEA Crane project through collaborative efforts with Science Applications International Corporation, Purdue University, and New Mexico Institute of Technology is analyzing data and building a database of publicly available reliability results from consumer, military, and aerospace electronics in order to assist the industry in quantifying the risks associated with choices of materials, processes, components and assemblies for Pb-free and mixed solder applications. This collaborative research and development project in lead-free soldering has specific relevance to the reliability of rework and repair processes of new Pb-free, legacy SnPb, and mixed solder systems using various combinations of Pb-free and legacy finished components and solder alloys in military systems.

The goal of the Crane NAVSUP project is to:

- Develop a critical evaluation of new/existing reliability data as it is developed
- Fill research gaps in tin whisker formation
- Examine rework of Pb-free and Sn-Pb solder joints, looking for microstructure evidence of damage in reworked solder joints
- To assist in developing a strategy for DoD on military electronics affected by the lead free initiative

The primary purpose of the 30 test vehicle add-on is to perform multiple pass SnPb rework 1 and 2 times on random Pb-free DIP, TQFP-144, TSOP-50, LCC and QFN components from SAC305 and SN100C soldered assemblies. BEST Inc will perform the QFN rework for NAVSEA Crane.

In a related test, the Crane project plans to stiffen the 9 Salt Fog test vehicles from the JCAA/JGPP Lead-Free Solder Project to military specifications and rerun the vibration test previously performed. The Crane project would like to see how standard circuit board stiffening affects the vibration test results previously observed.

NOTE: The Salt Fog board residues remained on the boards for over two years, etching the solder joints on the 9 test vehicles to varying degrees. The QFP-208 solder joints look very poor. Others look acceptable. The Crane project is aware of this issue and will take this into account when comparing data to un-stiffened boards.

The breakdown of the 30 test vehicles is as follows:

24 each built with SAC305
06 each built with SN100C

The reworked test vehicles will be integrated into the NASA-DOD -55°C to +125°C thermal cycling testing (Rockwell Collins). Drop testing (Celestica) will be run as an identical parallel test to minimize variation between the NASA-DOD and Crane test data. Celestica will perform the vibration testing for Crane as the NASA-DOD testing facility cannot accommodate the Crane vibration test vehicles.

The breakdown of the test vehicles is as follows:
Thermal Cycling -55°C to +125°C

- 4 each SAC305
- 4 each SN100C

Vibration Testing (9 each SAC305)
Drop Testing (9 each SAC305)
Reserved for as manufactured testing, control and rework process development

- 2 each SAC305
- 2 each SN100C

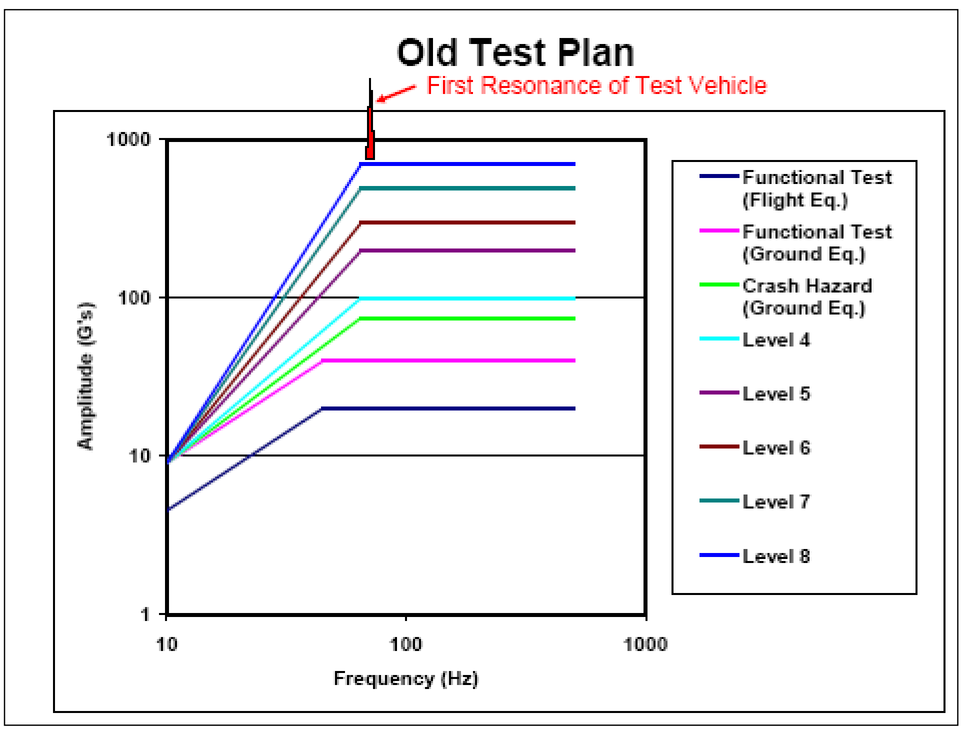
The goal of this testing is to generate initial data supporting the qualification of existing SnPb rework procedures for all military hardware built with Pb-free processes through analysis of thermal cycling, vibration, and drop test data, with subsequent microsection analysis. Questions to be answered by this testing include:

1. Effect of X1 and X2 rework on assembly reliability as tested by thermal cycle, vibration, and drop test.
2. Are Pb-free assemblies reworked with SnPb as reliable as as-built lead free hardware?
3. How residual Pb-free solder contamination levels in SnPb joints after X1 and X2 rework correlate to reliability? Each rework cycle should reduce contamination levels and analysis of solder samples will tell residual levels.
4. Effect of X1 and X2 SnPb rework on surface mount land thickness (copper erosion) by cross section.
5. Visual evidence of X1 and X2 rework damage to 170$_{Tg}$ laminate.

Test Vehicle Break Out
Due to the various types of test vehicles being assembled, BAE Systems will assemble the test vehicles in multiple batches.

Table 5 Test Vehicle Batch Key
Batch F
Batch I

Appendix E – Mechanical Shock Procedure Change

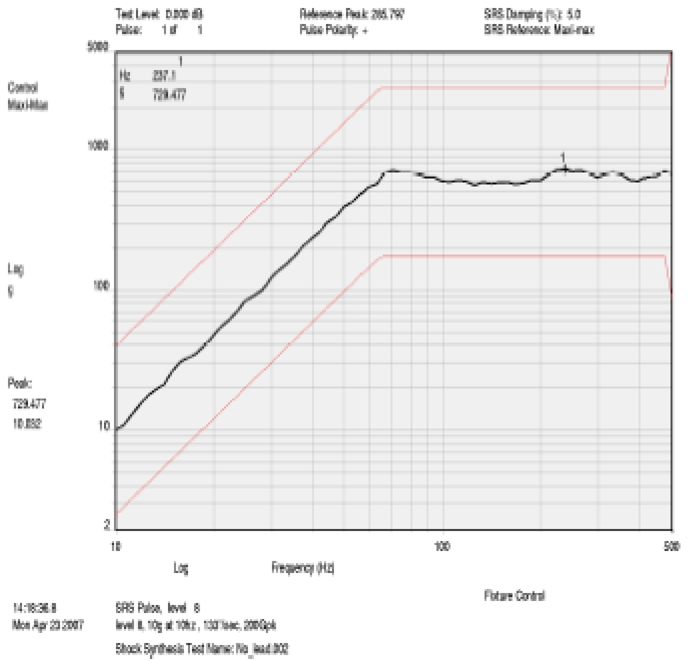


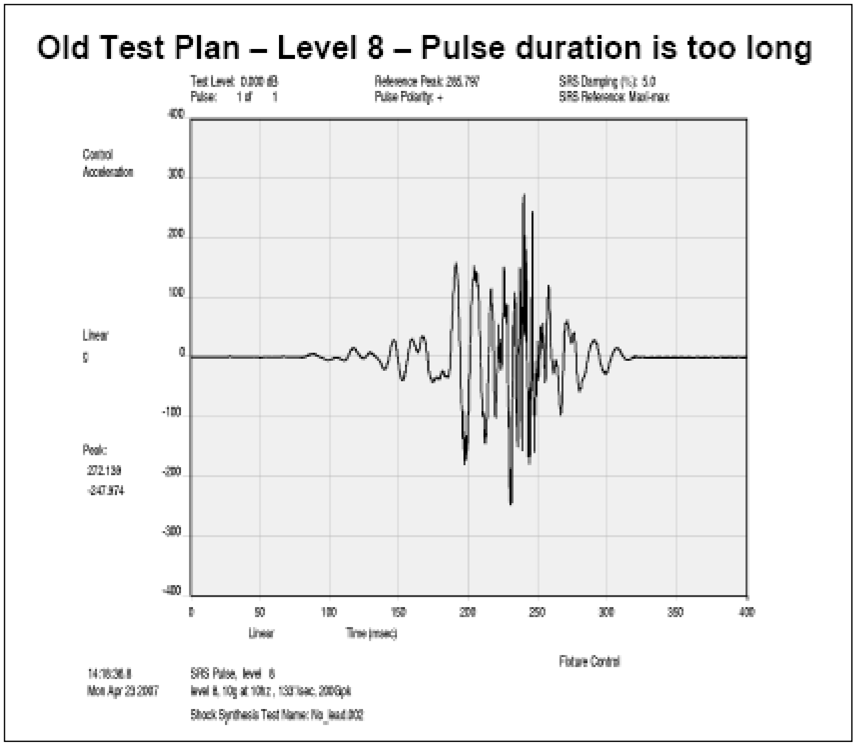
Old Test Plan

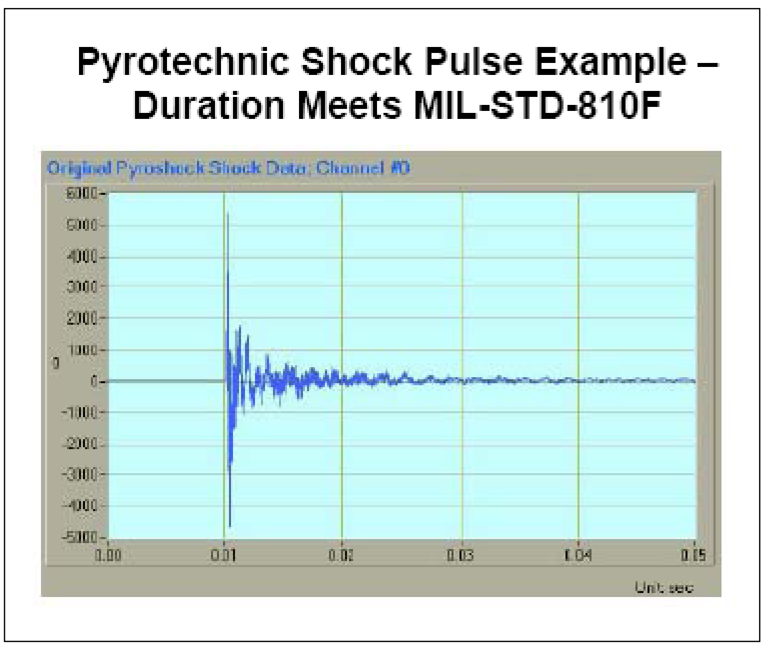
Test	Initial G	Slope	Peak G	Ts (ms)	Cross-Over Freq.*	Shocks
Functional Test for Flight Eq.	4.5	6.0	20	15-23	45	100
Functional Test for Ground Eq.	9.0	6.0	40	15-23	45	100
Crash Hazard Test for Ground Eq.	9.0	6.8	75	8-13	65	100
Level 4	9.0	7.75	100	15-23	65	100
Level 5	9.0	9.97	200	15-23	65	100
Level 6	9.0	11.28	300	15-23	65	100
Level 7	9.0	12.92	500	15-23	65	100
Level 8	9.0	14.00	700	15-23	65	100 or more till majority fail
* Cross-over freq. may change dependent on resonant frequency of TV						

It is very difficult to meet both the SRS shape and the pulse duration for this test (even with explosives). Pulse duration approximately equals inverse of lowest SRS frequency. 10 Hz SRS requirement means pulse duration >100 msec.

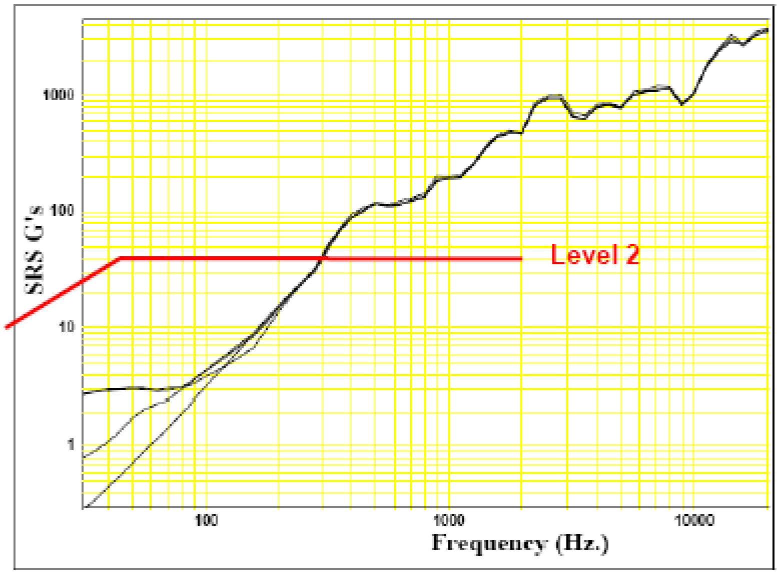
Old Test Plan – Level 8 – Electrodynamic Shaker SRS



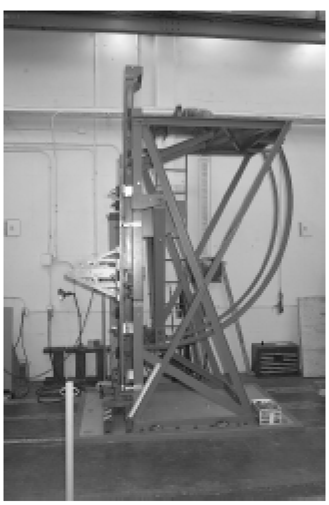

Old Test Plan – Level 8 – Pulse duration is too long
Pulse Polarity: +
SRS Reference: Maxi-max
Control
Acceleration
Linear
Peak:
272.139
-247.974
0
100
200
300
400
-100
-200
-300
-400
0
50
100
150
200
250
300
350
400
Linear
Time (msec)
Fixture Control
Mon Apr 23 2007
SRS Pulse, level 8
Shock Synthesis Test Name: No_lead.002


Pyrotechnic Shock Pulse Example – Duration Meets MIL-STD-810F
Original Pyroshock Shock Data; Channel #0
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
0.00
0.01
0.02
0.03
0.04
0.05
Unit: sec

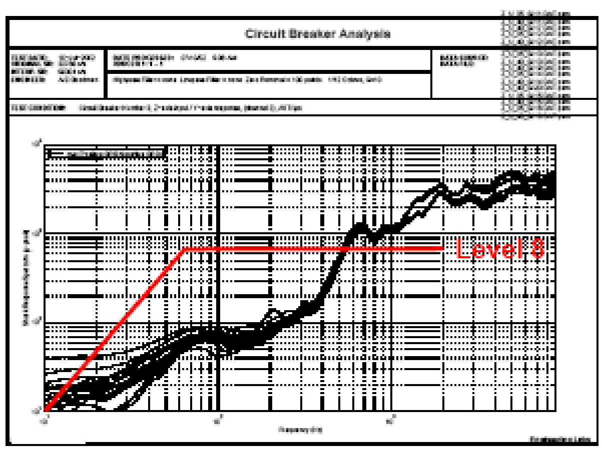
Pyrotechnic Shock SRS – does not satisfy MIL-STD-810F – very hard to control SRS shape – very expensive



Pendulum Shock Test Machine
Boeing Structural Dynamics Lab



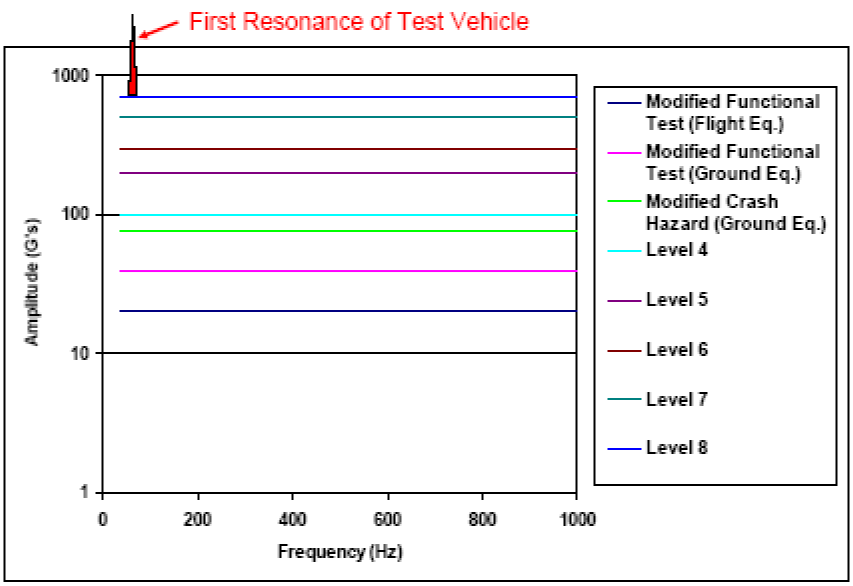
Designed to simulate pyrotechnic shock – notice that intermediate frequencies are missing – very hard to control SRS shape



MIL-STD-810F

"If the test item has no significant low frequency modal response, it is permissible to allow the low frequency portion of the SRS to fall out of tolerance in order to satisfy the high frequency portion of the SRS, provided the high frequency portion begins at least one octave below the first natural mode frequency of the test item."

Modified Test Plan - SRS Inputs

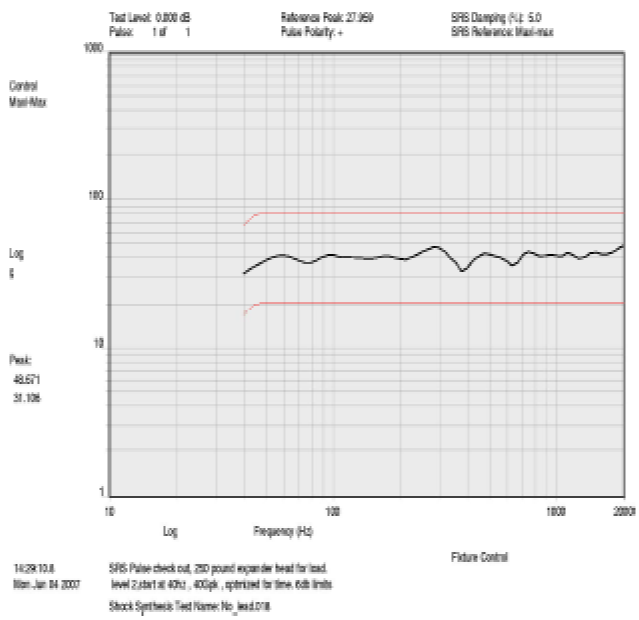


Modified Test Plan

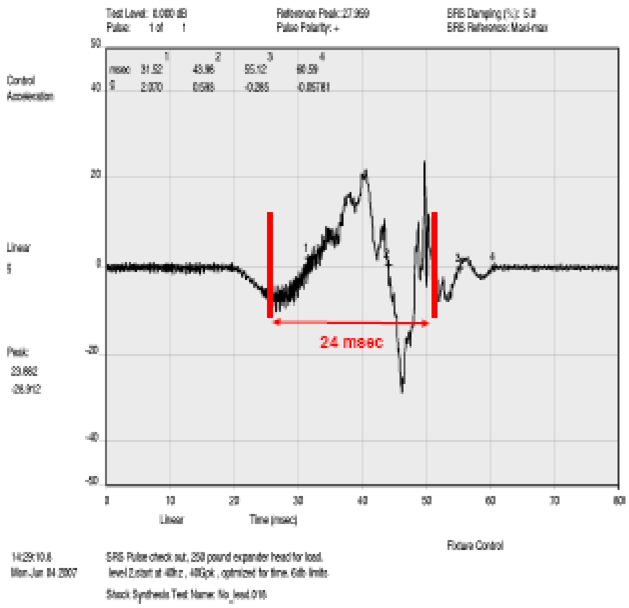
Test	Amplitude (G's)	Te (milliseconds)	Shocks Per Level
Modified Functional Test for Flight Eq.	20	<30	100
Modified Functional Test for Ground Eq.	40	<30	100
Modified Crash Hazard Test for Ground Eq.	75	<30	100
		<30	
Level 4	100	<30	100
Level 5	200	<30	100
Level 6	300	<30	100
Level 7	500	<30	100
Level 8	700	<30	100 or more till majority fail

*** Cross-over freq. may change dependent on resonant frequency of test vehicle**

Modified Test Plan – Level 2



Modified Test Plan – Level 2

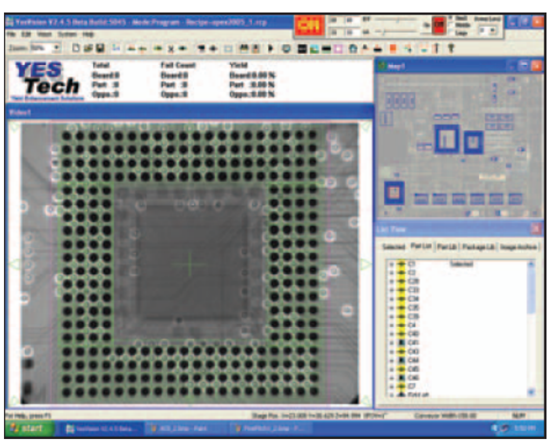


- Modified test plan ensures:
  - All major bending modes will be excited (not true for pyroshock or pendulum shock)
  - Good control of the SRS shape is maintained (not true for pyroshock or pendulum shock)
  - Pulse duration and SRS shape called out in MIL-STD-810F will be closely approximated

Appendix F – Area Array X-Ray Analysis

Machine:
YESTech YTX-5000 model in-line x-ray machine

- X-Ray Tube:
  - Sealed reflection target
  - 130 Kv, 5 micron spot size
  - 39-watt max. output
- X-Ray FOV:
  - 0.2” to 1.5” variable



Program settings:

All x-ray inspections are performed at 75kV and 40µA.

- Inspection set-up:
  - QFN
    1. Inspect each lead bank for joint presence and bridging
       - Threshold = 172
    2. Inspect center pad for voids (flag if > 25%)
       - Threshold = 151

  - CSP-100
    1. Inspect blocks of balls (5 x 5) for presence and bridging
       - Threshold = 120
    2. Inspect shape of individual balls for consistency
       - Threshold = 120
       - Shape Limit = 1.45
    3. Inspect size of individual balls
       - Threshold = 120
       - Size Range = .125 mm^2 - .175 mm^2
         - Translates to ∅ range of approx. 0.40 mm – 0.47 mm
           - Loose component ball size is 0.46 mm
           - Average x-ray ball size is .45 mm
    4. Inspect individual balls for voiding (flag if > 10%)
       - Threshold = 100

  - BGA-225
    1. Inspect blocks of balls (3 x 3 and 3 x 4) for presence and bridging
       - Threshold = 95
    2. Inspect shape of individual balls for consistency
       - Threshold = 95
       - Shape Limit = 1.45
    3. Inspect size of individual balls
       - Threshold = 95
       - Size Range = .400 mm^2 - .525 mm^2
         - Translates to ∅ range of approx. 0.71 mm – 0.82 mm
           - Loose component ball size is 0.75 mm
           - Average x-ray ball size is .81 mm
    4. Inspect individual balls for voiding (flag if > 10%)
       - Threshold = 75

Shape Limit:
For a perfect circle, the shape value will be 1. As a shape deviates from a perfect circle, the shape value will increase. It is unknown exactly how the value is calculated, but the equipment/software vendor recommends using a shape limit of 2 or less.

Ball Size:
The measured size of the ball in the x-ray image is dependent on several factors:

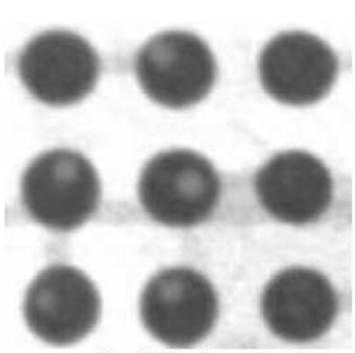
- Original component ball size
- Amount of solder added at assembly
- Weight of component (squish factor)
- X-Ray parameters (power)
- Background (extent to which ball contrasts with surrounding image)
- Threshold value (ball edges are 'feathered', and affected by small changes in threshold)

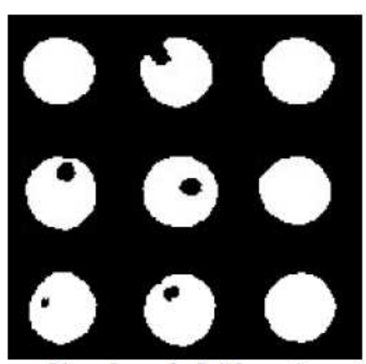
With some degree of effort, the measured balls size from the x-ray image may be adjusted to match the actual ball size by manipulating the power and threshold settings. This is not necessary, however, and setting relative limits to detect defects on an optimized image is suitable.

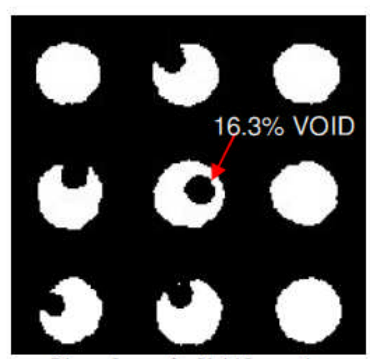
The automated x-ray system applies inspection algorithms to binary images to determine the presence of defects. The inspections include:

- Looking for the expected number of distinct shapes within the inspection area and close to the expected size
- Checking the overall size (diameter / pixel count) of the shapes found
- Checking the 'roundness' of the shapes found
- Looking for and evaluating size of voids within those shapes found

The algorithm requires that a threshold value be set to define what is, and what is not, solder. This will be used to create the binary images from the raw x-ray images. This value is determined by the programmer.

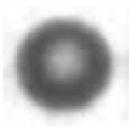

Raw X-Ray Image


Binary Image for Ball Inspection

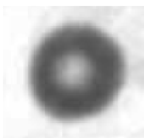


Binary Image for Void Inspection

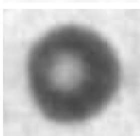
The first image above is the raw x-ray image of part of a BGA. Voids within the solder ball are clearly visible as lighter spots within the joints. The second image is the binary image used to determine the presence, size, and shape of the solder balls. A threshold value has been set (based on the contrast between solder and surrounding areas) for this image such that the resulting shapes in the binary image match the size of the solder balls in the raw x-ray image. The third image is the binary image used to evaluate the presence and size of voids. Because the contrast between the voids and the surrounding solder is different from the contrast between the solder ball and the surrounding area, the threshold level is different, and a different image is created. This threshold value is set such that the resulting voids in the binary image match the size of the voids in the raw x-ray image.



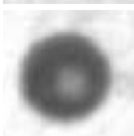
31.9%



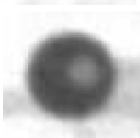
26.7%



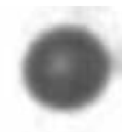
25.0%



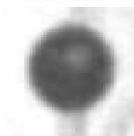
20.9 %



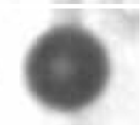
16.3%



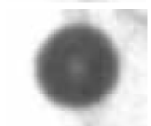
13.2%



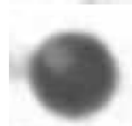
11.8%



7.9%

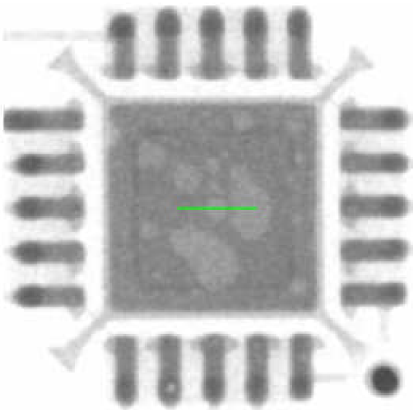


3.2%

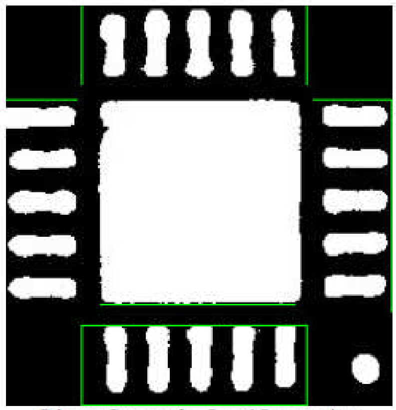


Bad Shape Defect

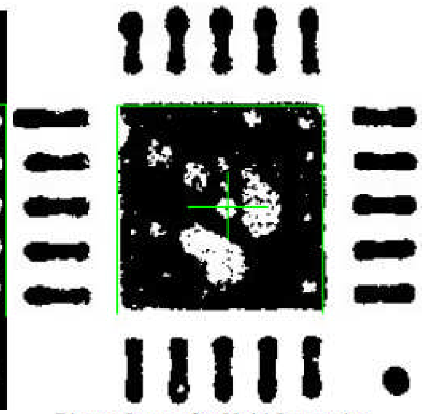
Similar to the BGA inspection, the images below are for QFN x-ray inspection. The first image is the raw x-ray image, the second is the binary image for lead bank inspection, and the third is the binary image for void detection. The combined area of the voids shown in this example was calculated at 16%.



Raw X-Ray Image



Binary Image for Lead Inspection



Binary Image for Void Inspection

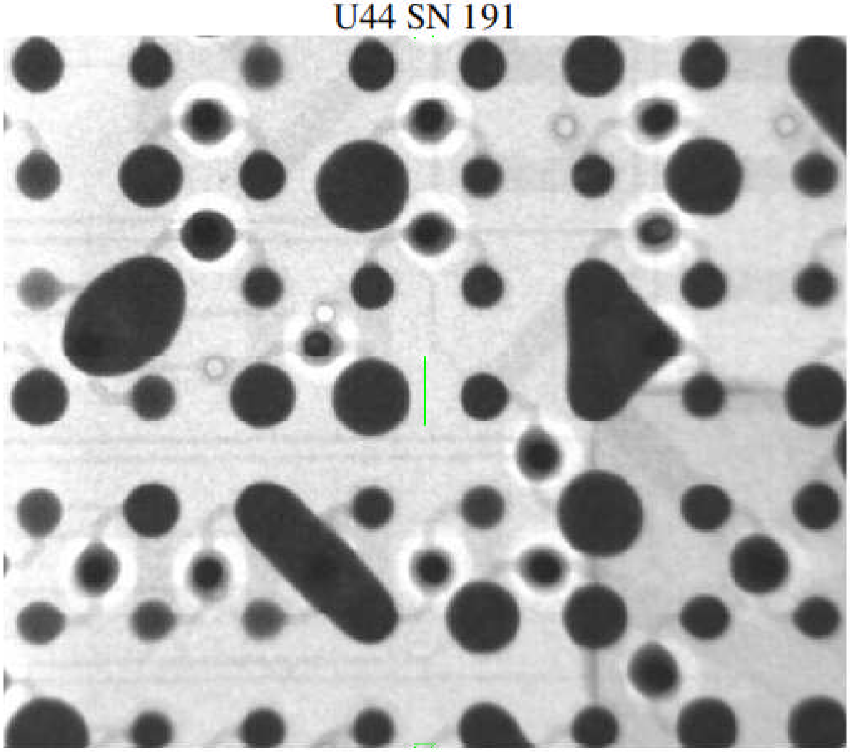
<u>Results:</u>

- **Batch A**

  <u>Bridging:</u>

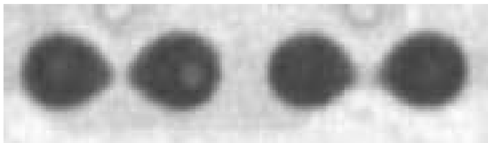
  The only obvious voids identified were on U44 of SN191, where something apparently went wrong:

U44 SN 191



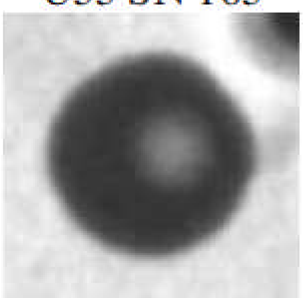
There was also some implied bridging. This tear-drop shape (below) was not uncommon and fell along the paths of electrical connection on the bottom side of the package:

U35 SN 193

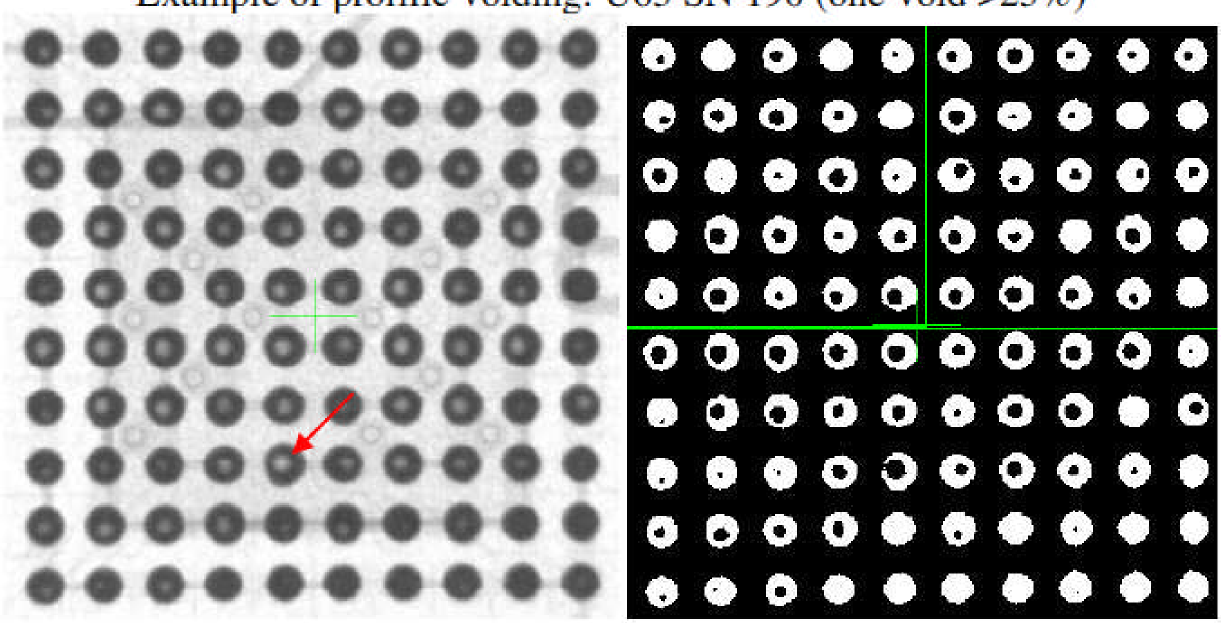


<u>Voids:</u>
Several voids >25% on BGAs, low voiding (~20% or less) on QFNs
There were numerous voids in both the CSP-100 and BGA-225 packages.
Voids up to 16.4% were seen in the BGA-225 balls.

U55 SN 165

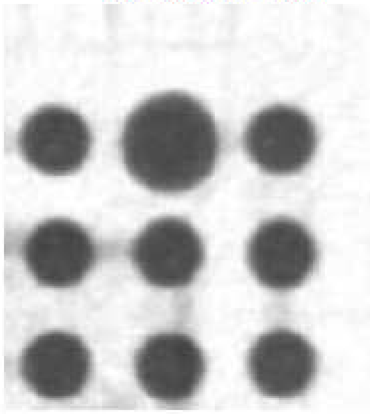


Example of prolific voiding: U63 SN 190 (one void >25%)



Other:
An excessively large solder ball was found. The diameter of this ball is 0.65 mm (average is about 0.45 mm for this package).

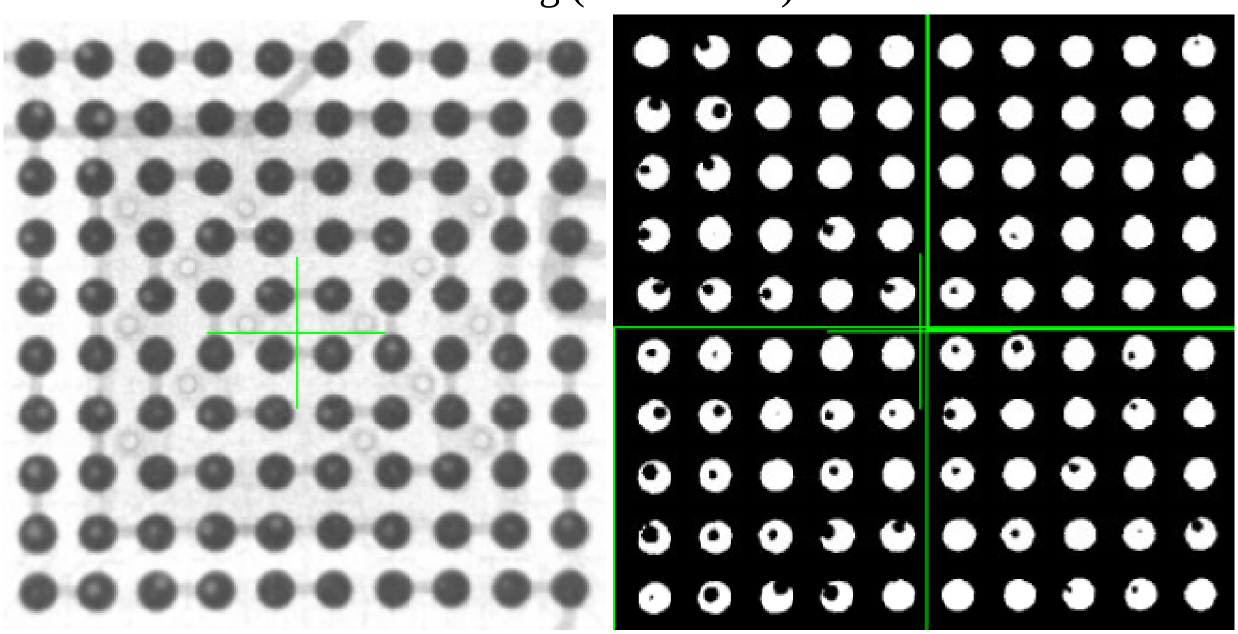
U13 SN 186



- **Batch B1**
  Bridging:
  No bridging detected

  Voids:
  No voids >25% on BGAs, low voiding (~20% or less) on QFNs

SN 138 exhibits the most voiding (none >25%)



Other:
No other anomalies detected.

- **Batch B2**
Bridging:
No bridging detected

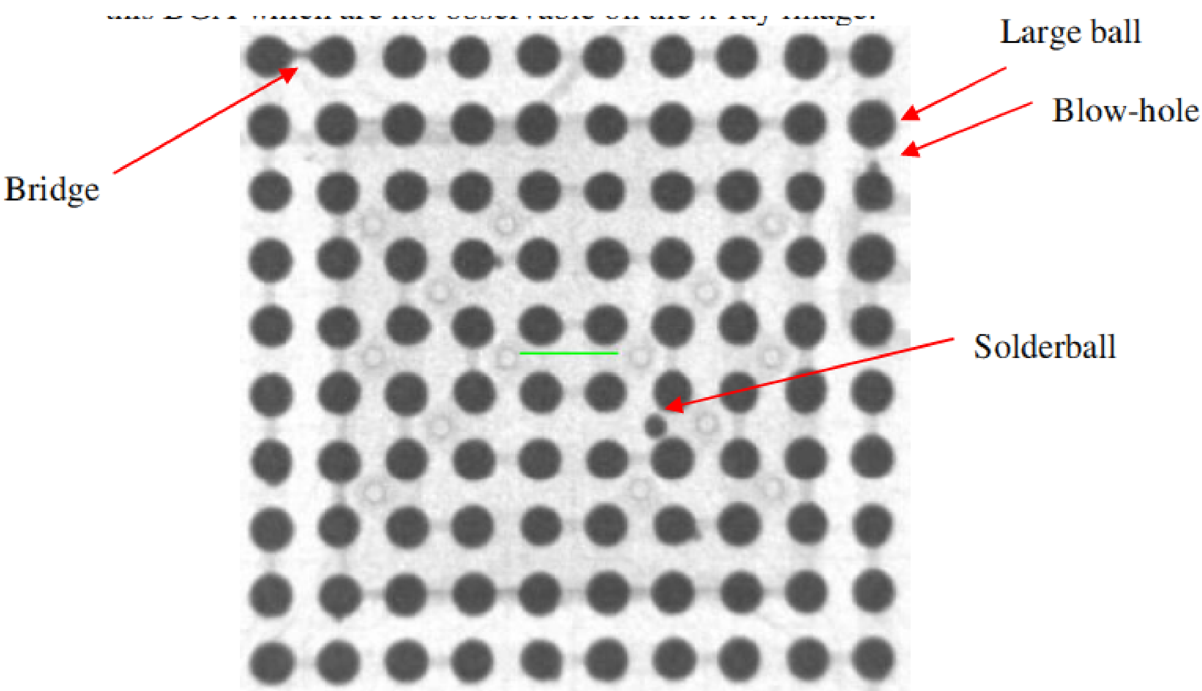
Voids:
No voids >25% on BGAs, low voiding (~20% or less) on QFNs

Other:
No other anomalies detected.

- **Batch C**
Bridging:
No bridging detected.

Voids:
No voids >25% on BGAs, low voiding (~20% or less) on QFNs

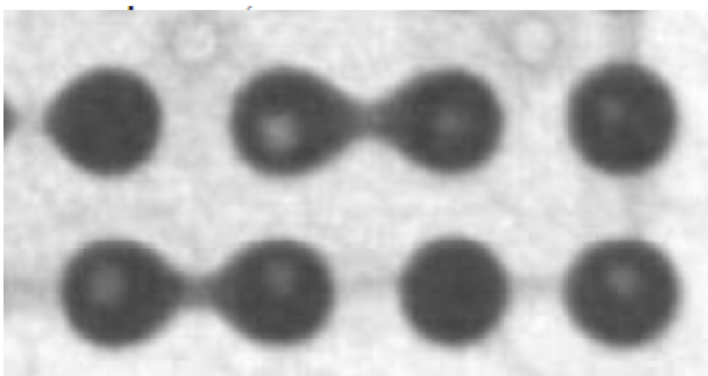
Other:
SN 1, U63 has a solder ball (extra) violating minimum electrical clearance(?), a solder ball larger than normal (not excessive), a blow-hole on a ball, and a bridge. There were also several small solderballs under this BGA which are not observable on the x-ray image.



- **Batch D**
  Bridging:
  One board had bridging on one component (12 bridges on U36)

  Voids:
  No voids >25% on BGAs, low voiding (~20% or less) on QFNs
  Other: No other anomalies detected.

- **Batch E**
  Bridging:
  One board had bridging on one component (bridges appear to be along the metallization of the component)



  Voids:
  Low voiding (~20% or less) on QFNs
  4 units have voids greater than 25% on U63

  Other:
  No other anomalies detected.

- **Batch F**
  Bridging:
  No bridging detected

  Voids:
  No voids >25% on BGAs, low voiding (~20% or less) on QFNs

  Other:
  No other anomalies detected.

- **Batch G**
  Bridging:
  No bridging detected

  Voids:
  No voids >25% on BGAs, low voiding (~20% or less) on QFNs

  Other:
  No other anomalies detected.

- **Batch H**
  Bridging:
  No bridging detected

  Voids:
  No voids >25% on BGAs, low voiding (~20% or less) on QFNs

  Other:
  No other anomalies detected.

- **Batch I**
  Bridging:
  No bridging detected

  Voids:
  No voids >25% on BGAs, low voiding (~20% or less) on QFNs

  Other:
  One slightly larger ball (diameter of .54mm) on SN 107 U33, not excessive.

SUMMARY:
There were several true defects found, from both special causes (misinstalled parts) and common causes (voiding, solder ball variation, etc.).

The amount of voiding in BGA and CSP solder joints varied greatly, although the most common and worst cases of voiding were typically found in the U35 and U63 locations of the CSP component.

Near bridging, implied bridging, and true bridges were common on the CSP components. It appears that the physical geometry of the components and the traces running between pads on the bottom of the component promoted bridging along these traces (despite the presence of solder mask covering the traces).